Study on exploring the possible employment implications of connected and automated driving - Final Report

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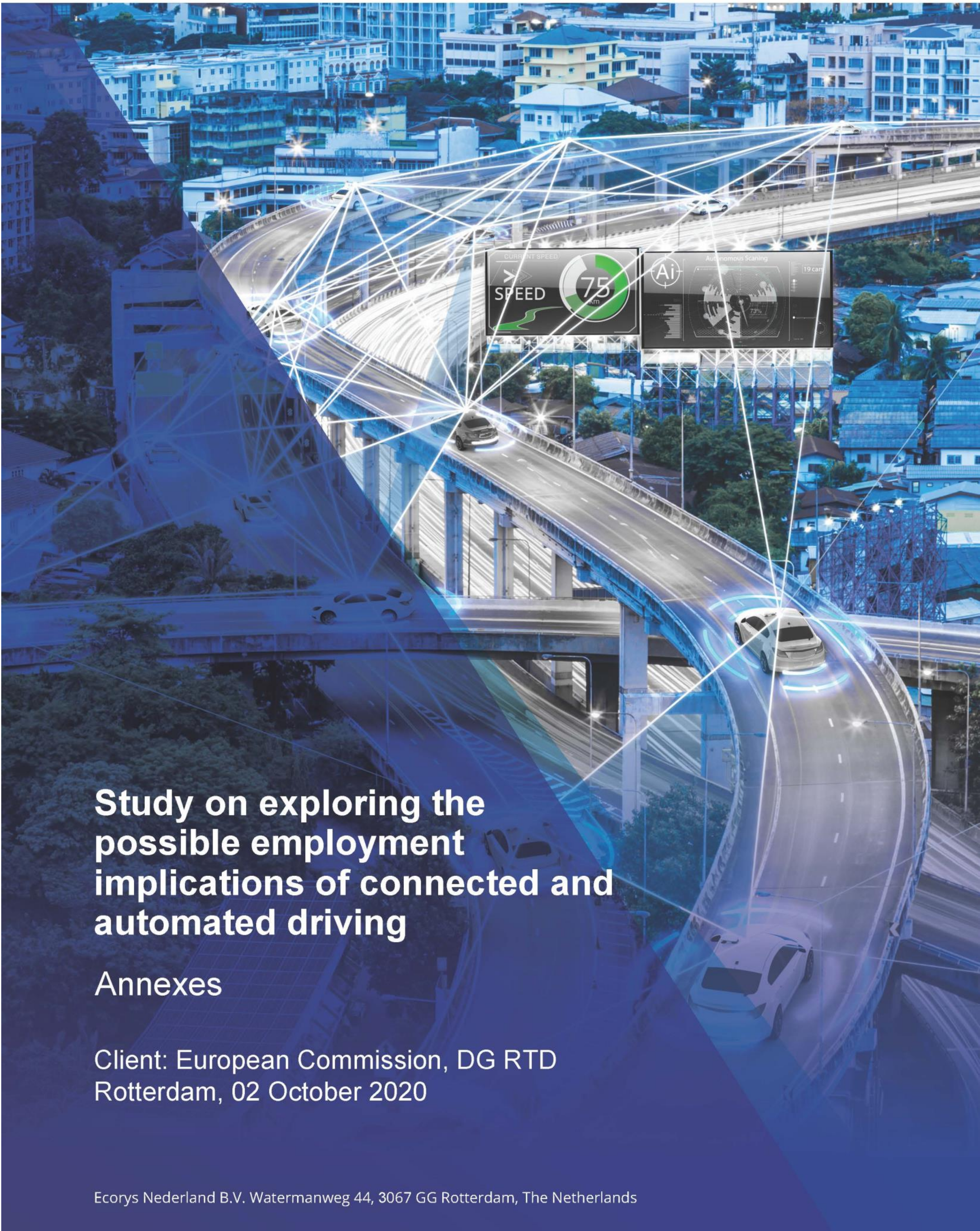

Study on exploring the possible employment implications of connected and automated driving

Annexes

Client: European Commission, DG RTD
Rotterdam, 02 October 2020

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Client: European Commission, Directorate General for Research & Innovation, C.5 Ecological and Social Transitions

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Rotterdam, 02 October 2020

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Annex A – Data Collection Framework

Data inputs of the Scenario Model

Data inputs for the Scenario Model are listed in Table A.1

It can be seen that several parameters have been estimated by using data already available from other modelling tools as well as data collected during the analysis carried out for different European transport modelling exercises.

Other variables proved difficult to be collected as they are specifically related to cost and performance of CAD vehicles by type of automation (SAE) level. Data from literature on these variables is not available yet and therefore assumptions have been performed on the basis of the input collected during the stakeholders' consultation (i.e. interviews and workshops).

The Scenario Model also includes several parameters reflecting behavioural responses (e.g. elasticity of demand of CAD vehicles with respect to elements like cost, regulation, etc.). These parameters cannot be found in data sources. There is plenty of literature on studies and models concerning the uptake of CAD vehicles to be consulted. However, as scopes diverge, most of the literature available lacks integral overviews neither produces quantitative data. Furthermore, most of these parameters are not "objective" entities (like e.g. the price of a vehicle) but a synthetic, mathematical, representation of behavioural responses or other circumstances that affect demand of CAD vehicles. Given the assumptions on other inputs, there are some values of the elasticities allowing to obtain the expected levels of penetration (more "optimistic" in some scenarios, more "pessimistic" in other scenarios). Therefore, certain parameters are a sort of "leverages" of the model which could be used to steer the model's reaction in view of the specific scenarios outcomes.

Table A.1 Data inputs for Scenario Model

Input Variable	Input Units	Model Variable	Disaggregation	Source
Base population	%	Share of individuals by socio-demographic group	Year Income level Car availability Living area	Other European scale modelling tools
Car Availability	Cars/person	Car Availability per Group	Full Partial No Semi	Other European scale modelling tools
Personal mobility	Trips per year /person	Trip rates by group and purpose	Income level Car availability Trip purpose	Other European scale modelling tools
Base travel distances	km/trip	Average travel distances by group and purpose	Income level Car availability Trip purpose Living area	Other European scale modelling tools
Base truck market share	%	Truck market share on tonnes	Year Freight type: International National Regional Local distribution	Other European scale modelling tools
Car occupancy factors	persons/car	Average cars occupancy factors by purpose	Vehicle type Income level Car availability Trip purpose Living zone	Other European scale modelling tools
Bus occupancy factors	persons/bus	Average bus occupancy factors	Bus Mode	Other European scale modelling tools
Load factors	tonnes/truck	Average truck load factors	Truck Type Zone type	Other European scale modelling tools

Input Variable	Input Units	Model Variable	Disaggregation	Source
Usage of truck types	%	Share of truck type for each Freight type	Freight type Truck type Zone type	Other European scale modelling tools
Use of road vehicles	Miles/Year	Average Yearly Mileage by mode	Vehicle type	Cars: https://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/distance-travelled-by-car.html Taxi: https://www.insuretaxi.com/2016/08/taxi-driver-survey-2016/ Car sharing cars: https://circular-impacts.eu/sites/default/files/D4.2_Case-Study-Carsharing_FINAL.pdf Buses: http://www.nasemore.com/wp-content/uploads/2018/11/20.-Potkany-Hlatka-Debnar-Hanzl.pdf Trucks: https://www.assotir.it/attachments/article/275/14-08-06_costi_minimi_mese_luglio%202014.pdf Assumptions for CAD vehicles
Road vehicle Purchase cost	Euro	Vehicle Purchase Cost by Road Mode	Year Vehicle type Powertrain	Cars: https://theicct.org/publications/european-vehicle-market-statistics-20182019 Buses: http://www.nasemore.com/wp-content/uploads/2018/11/20.-Potkany-Hlatka-Debnar-Hanzl.pdf Trucks: https://www.tuttotrasporti.it/content/tuttotrasporti/it/listini-nuovo/CostiEsercizio.8-3680.html Assumptions for CAD vehicles
Road vehicles Maintenance Cost	Euro/year	Vehicle Maintenance Cost by road mode	Vehicle type Powertrain	Cars: (https://www.leaseplan.com/corporate/~/media/Files/L/Leaseplan/documents/news-articles/2019/2019-car-cost-index.pdf) Trucks: https://www.assotir.it/attachments/article/275/14-08-06_costi_minimi_mese_luglio%202014.pdf) Buses: http://www.nasemore.com/wp-content/uploads/2018/11/20.-Potkany-Hlatka-Debnar-Hanzl.pdf; https://www.kennisplatformtunnelveiligheid.nl/wp-content/uploads/2015/02/civitas_policy_note_clean_buses_for_your_city.pdf Assumptions for CAD vehicles
Road vehicles Registration taxes	Euro/year	Registration taxes by Mode	Year Vehicle type Powertrain Automation level	Cars: https://www.acea.be/uploads/news_documents/ACEA_Tax_Guide_2019.pdf Trucks: https://www.acea.be/uploads/news_documents/ACEA_Tax_Guide_2019.pdf Assumptions for CAD vehicles

Input Variable	Input Units	Model Variable	Disaggregation	Source
Road vehicles Energy Cost	Euro/vkm	Vehicle Energy Cost by road mode	Year Vehicle type Powertrain	Cars: https://www.leaseplan.com/corporate/~/media/Files/L/Leaseplan/documents/news-articles/2019/2019-car-cost-index.pdf Buses: http://www.nasemore.com/wp-content/uploads/2018/11/20.-Potkany-Hlatka-Debnar-Hanzl.pdf Trucks: https://www.assotir.it/attachments/article/275/14-08-06_costi_minimi_mese_luglio%202014.pdf) Assumptions for CAD vehicles
Drivers cost	Euro / year	Truck and bus driver cost	Truck type Bus type	Cars: https://ec.europa.eu/transport/sites/transport/files/2016-09-26-pax-transport-taxi-hirecar-w-driver-ridesharing-final-report.pdf) Bus: https://ec.europa.eu/transport/sites/transport/files/modes/road/studies/doc/2016-04-passenger-transport-by-coach-in-europe.pdf Trucks: https://www.assotir.it/attachments/article/275/14-08-06_costi_minimi_mese_luglio%202014.pdf)
Autonomous fleet system management cost	Euro / year	Truck and Bus autonomous fleets management cost	Year Truck type Bus type	Data not available
Road vehicles average lifetime	Years	Average Road vehicle lifetime	Vehicle type Truck type Bus type Powertrain	Cars: http://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/autoritratto/autoritratto-2018.html) Buses: https://tfl.gov.uk/corporate/publications-and-reports/buses-performance-data Trucks: http://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/autoritratto/autoritratto-2018.html
Accident rates	accident/vkm	Base accident rate for level 0 vehicles	Vehicle type Truck type Bus type	Other European scale modelling tools

Data inputs of the ASTRA model

Data inputs for the ASTRA Model, the Component Model and the Mobility Service Model are listed in Table A.2

Table A.2 Data inputs for the ASTRA Model, the Component Model and the Mobility Service Model

Input Variable	Unit	Source	Linked to
New Vehicles per category[2] and automation level	Vehicles	Scenario Model	Component Model; ASTRA: Tax revenues
Vehicles stock per category, technology and automation level	Vehicles	Scenario Model	Component Model; ASTRA: Tax revenues
Distance travelled by passengers per passenger mode[3]	Passenger-kilometre	Scenario Model	ASTRA: Input-Output Table, Transport Investment
Freight distance per freight mode[4]	Tonne-kilometre	Scenario Model	ASTRA: Input-Output Table, Transport Investment
Road freight traffic flow per truck size and automation level	Vehicle-kilometre	Scenario Model	Mobility Service Model
Car Purchase expenditure	Euro	Scenario Model	ASTRA: Transport Consumption & Investment
Bus Purchase expenditure	Euro	Scenario Model	ASTRA: Transport Investment
HDV purchase expenditure	Euro	Scenario Model	ASTRA: Transport Investment
LDV purchase expenditure	Euro	Scenario Model	ASTRA: Transport Investment
Private car costs (maintenance, insurance, registration tax)	Euro	Scenario Model	ASTRA: Private transport consumption
Passenger transport expenditure by passenger mode	Euro	Scenario Model	Mobility Service Model; ASTRA: Private transport expenditures & consumption
Passenger and freight transport energy and energy tax expenditures	Index to 2020	Scenario Model	ASTRA: Private transport consumption, tax revenues
Road Freight operating costs	Euro/ vehicle-kilometre	Scenario Model	Mobility Service Model; ASTRA: Input-Output Table
Passenger road Toll revenues	Euro	Scenario Model	ASTRA: Government revenues
Freight road Toll revenues	Euro	Scenario Model	ASTRA: Government revenues
Investment in CAD production facilities	Euro	Various sources (see Annex C)	ASTRA: Investment
Costs for CAD infrastructure components	Euro/item; Euro/km	Various sources (see Annex C)	Investment in CAD infrastructure
Length of the road network per country	km	Transport in Figures (2019)	Investment in CAD infrastructure
Costs of vehicle modules per category and technology	Euro	Various sources (see Annex C)	Component Model
Share of imported vehicles	%	OICA (2019)	Component Model
Share of exported vehicles	%	OICA (2019)	Component Model

2 Vehicle categories: Private cars, commercial cars, urban busses, long-distance coaches, light-duty vehicles, and heavy-duty vehicles in four different size classes.

3 Passenger mode: Foot & Bike, Car, conventional bus, taxi, car sharing, automated Taxi, ride sharing, automated bus, train, air.

4 Freight mode: Truck, train, maritime, inland waterways.

Input Variable	Unit	Source	Linked to
Export of single vehicle components	%	CAM database	Component Model
Passenger transport services expenditures	Euro	Scenario Model	Mobility Service Model
Freight transport services operating costs	Euro / vkm	Scenario Model	Mobility Service Model

Nevertheless, we used various ways to fill data gaps and thus generate values that correspond as closely as possible to the real values. Below we have summarized several of these ways and their basic principles:

i. **Informed Assumptions**
An obvious alternative for direct data values is filling by "own" assumptions. However, it is important to note that we do not made the estimates without any knowledge base: For this reason, we call them "informed assumptions". We made them on the basis of qualitative statements from respondents of the interviews and participants of the workshops as well as with results of former modelling or earlier projects. The literature review gave us information for a more accurate estimation, too. This alternative was therefore suitable for cases in which at least qualitative information was available. For example, we built up our job shares in the synthesis model partly on informed assumptions of sector experts.

ii. **Comparable Variables**
In our researches there was also cases in which the originally searched variable is not available, but similar variables exist. From them we could draw conclusions, on the basis of which we can indirectly calculate the original values. This can be done, for example, by simple aggregation or disaggregation (e.g. costs for single components versus prices of whole systems). A condition was that the alternative values were actually comparable, for example by forming the totals or subsets of the original values or by allowing further indirect conclusions. If we had no direct employment numbers for NUTS zones to build the regional keys, we used vehicles to calculated the employees per vehicle, for instance.

iii. **Extrapolations**
Extrapolation was a possible alternative if we know of quantifiable case studies that can serve as "prototypes" for a larger number of similar elements. This was the case, for example, when new mobility services today are only known as pilot projects (like robo-bus / taxi / HDV / LDV), which could exist in large numbers in the future. For example, driverless buses are currently only used in very limited cases. However, these "miniature" operations already show which employees are likely to be needed per vehicle.[5]

iv. **Typologies**
Typologies have similarities to projections, but by this we mean different cases, each of which stands for a special characteristic. Sometimes the number of typical values can be recorded, but not the total number. We saw, for example, that partly not all EU Member States were included in statistics. For each type of state, we assumed through informed assumption (see i. above) that relatively parallel conditions exist in the respective countries. For example, we built three generic country clusters for the calculation of job shares (see annex C).

5 One principal limitation of this option are possible economies of scale, i.e. increases in efficiency due to large numbers. These factors are often unknown or can only be approximated by informed assumptions.

The project partner Center of Automotive Management (CAM), which was a subcontractor of M-Five in this project, was involved to add information and fill data gaps. The main contributions were:

- Company database of vehicle and supplier industry (includes company name, Brand, Type of vehicle, Revenue 2018, Profit 2018, Region (EU / EFTA / ROW), Headquarter Location Number of Locations world-wide, number of employees);
- Innovation index (includes rankings of the level of maturity in terms of companies);
- global "unicorns" (includes CAD-related start-ups within and outside the EU);
- list of CAD services and technologies (includes hardware and software components as well as their costs and their relevance for the development of CAD);
- identification of cluster regions (includes regional information about locations of CAD-related companies);
- derivation of import market share (includes production volume worldwide and in Europe, share of turnover Europe, share of turnover outside Europe).

Employment parameters have partly been derived from German input-output tables. They have been adjusted for other countries to take account of varying income levels. Finally, they have been calibrated in order for modelling results to match empirical employment data for buses[6], taxis[7], light-duty and heavy-duty vehicles[8].

As automated services are not yet commercially available, there is no empirical data on employment generated by them. We have used non-driver employment parameters to create substitutes for this data gap. Non-driver employment intensity can be seen as an indicator of the general level of complexity of managing a particular type of transport service. We have therefore closely linked employment projections for automated services to non-driver employment of similar conventional services.

Data inputs of the NEMESIS model

In order to simulate the macroeconomic impact of Connected an Automated Driving (CAD), NEMESIS received data from two sources. Data concerning direct CAD development is coming from the Scenario model developed by TRT, and those related to investment in infrastructure are received from Astra (M-Five).

Regarding the development of CAD, we integrate in the NEMESIS model all data concerning expenditures by firms and households:

- for firms (bus, commercial cars, trucks) that are allocated as investment realised by the Land transport services;
- for households, the purchase of cars (considered as final consumption in the national accounts) as well as the expenditure in the different transport modes where allocated to their different consumption categories (NEMESIS consider 27 consumption categories).

6 Transport in Figures 2016.

7 Grimaldi, CERTeT Università Luigi Bocconi, Wavestone (2016), Study on passenger transport by taxi, hire car with driver and ridesharing in the EU, European Commission, Final Report, Study contract no. MOVE/D3/SER/2015-564/SI2.715085.

8 Transport in Figures 2016.

Table A.3 shows the most important input variables for the NEMESIS model.

Table A.3 Data inputs for the NEMESIS model

Source	Variable	Unit
Scenario Model	Car Purchase Households	Current € or 2010€
Scenario Model	Vehicle purchase Transport sector	Current € or 2010€
Scenario Model	Vehicle costs	Current € or 2010€
Scenario Model	Insurance costs	Current € or 2010€
Scenario Model	Energy costs	Current € or 2010€
Scenario Model	Operation and maintenance costs	Current € or 2010€
Scenario Model	Road Vehicle registration taxes	Current € or 2010€
ASTRA	Infrastructure investment	2005€

Source: SEURECO.

NEMESIS with its level of detail requires a large consolidated database for its functioning. Data are compiled from numerous sources and are post-processed for ensuring their whole accounting coherency. The main economic variables such as production, value added or employment are coming from Eurostat National Accounts and Labour force survey (2017). Trade data are based on WIOD (Timmer et al., 2015) and fiscal data are derived from DG TAXUD datasets (2017).

Data inputs of the Synthesis model

Data inputs for the Synthesis model are listed in Table A.4.

Table A.4 Data inputs for the Synthesis model

Input Variable	Unit	Source	Linked to
Employment in relevant NACE sectors per NUTS 2 zone	Number of persons employed	Transport in Figures (2019) / Various sources (see Annex C)	Synthesis Model
Total population per NUTS 2 zone	Number of persons	EUROSTAT (2019)	Synthesis Model
Taxi vehicles per NUTS 2 zone	Number of vehicles	Various sources (see Annex C)	Synthesis Model
Car sharing vehicles per NUTS 2 zone	Number of vehicles	Various sources (see Annex C)	Synthesis Model
Share of jobs within transport services	%	Various sources (see Annex C)	Synthesis Model

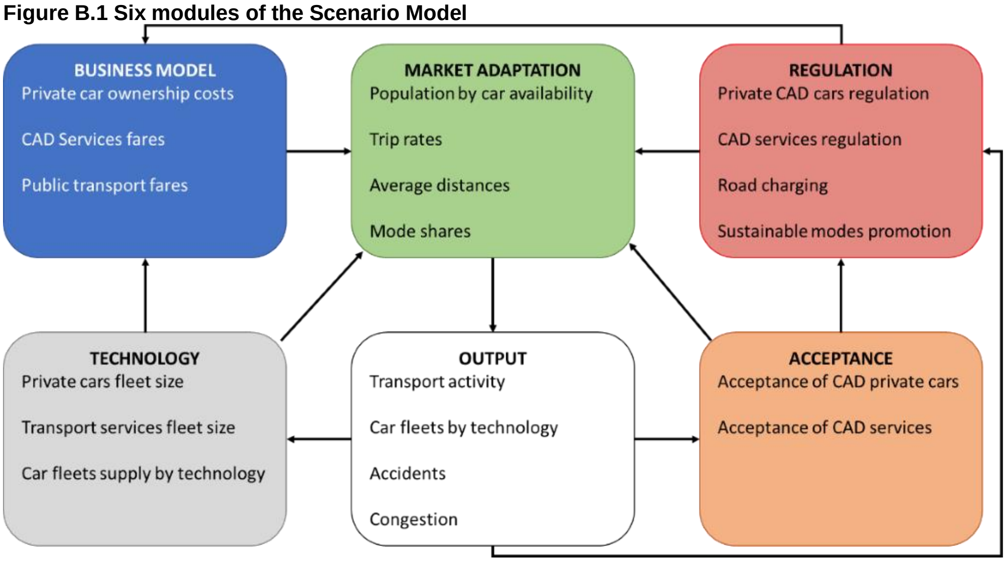
Annex C provides details on the modelling approach of the Synthesis model, including detailed assumptions based on literature and various studies. It includes all different components of the synthesis model such as the distribution of jobs as well as the regional distribution.

Annex B –The Scenario Model and Scenarios

Methodology of the scenario development

The **Scenario Model** is made of six main modules connected to each other as shown in figure.

Figure B.1 Six modules of the Scenario Model



The core of the model can be considered the **Market adaptation module**. This module receives inputs from other modules and computes how car ownership, mobility behaviour of individuals and transport choices of firms are modified because of the introduction of CAD vehicles. It is supposed that only CAD vehicles with Technology level 5 (CAD-5 from now on) generates a real change.

One input to the Market adaptation module comes from the **Technology module**, where the size and the composition of fleets are estimated from the supply side, i.e. according to the capacity of the automotive sector to provide vehicles with a certain technology. Technology also affects vehicles usage costs, which enters in the **Business model module**, where the cost for owning and using vehicles are computed as well as fares and rates (and availability) of transport services (car sharing and taxi) managed with CAD (technology level 5, i.e. driverless) cars. Costs and availability are affected by regulation, in form of indicators computed in the **Regulation module**. These indicators also affect behavioural responses. The level of regulation is largely an arbitrary choice at policy level, but it is supposed that the level of acceptance of CAD vehicles in the society influences the level of regulation: the more CAD are accepted and the less strict are rules (and vice-versa). The level of acceptance is defined in the **Acceptance module**, with the influence of the mobility conditions: it is expected that if the uptake of CAD vehicles demonstrates to reduce accidents and congestion, then acceptance is improved (and vice-versa). Using the inputs from the other modules, the Market adaptation module estimates various elements influencing mobility patterns. On the basis of these elements, new transport activity and fleet size and compositions are computed in the **Output module**.

The content of each module is described in the following sections.

The model is a System Dynamic one implemented in Vensim. The simulation period is between 2020 and 2050 with 1 year steps.

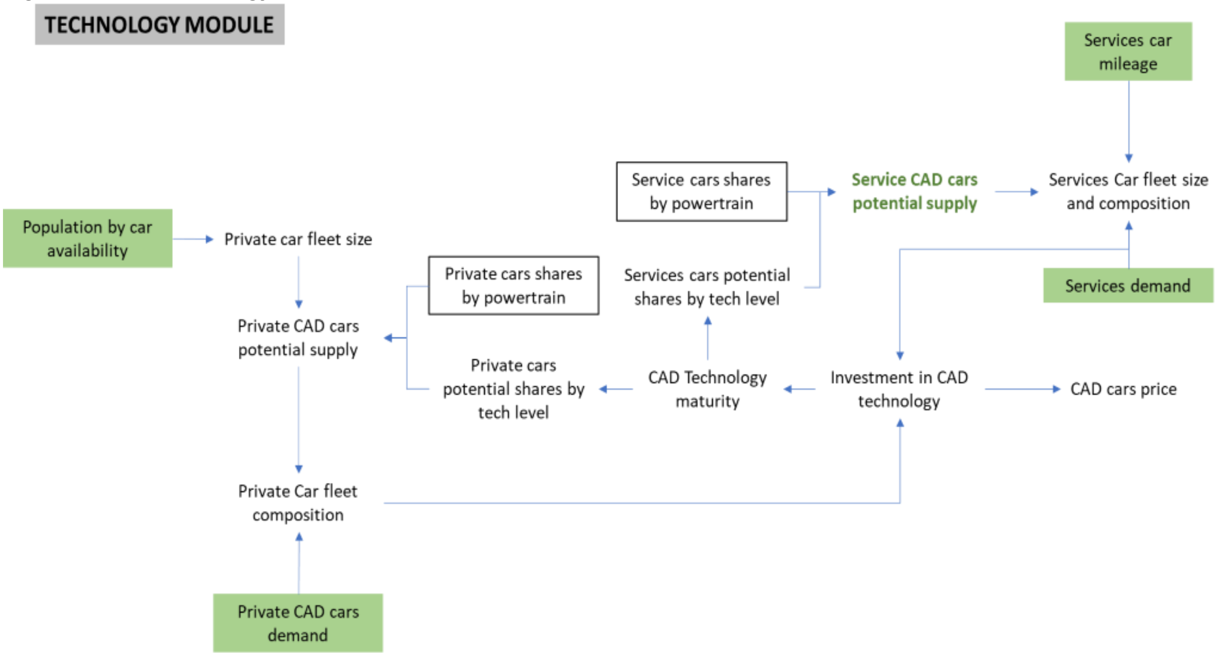
The model represents prototypical conditions of a generic country rather than specific countries. This means that some inputs like population are expressed in relative terms (e.g. share of individuals for a certain group) rather than in absolute terms. Different conditions that can be significant for the uptake of CAD vehicles can be represented by means of different initial values for a set of exogenous variables (e.g. distribution of population according to car availability, initial mode split, cars taxation).

The model is designed to provide relative variations of output variables. These relative variations will be applied to absolute values at country level in order to estimate the country-based inputs for ASTRA and/or the expected final outputs.

Technology module

The following figure provides an overview of the Technology module for the part regarding private cars.

Figure B.2 The technology module



Private cars fleet

Total size of private cars fleet is computed from population by car availability. Population is classified in four categories of availability: “full”, “semi-full”, “partial” and “no availability”. Full availability means that the car can be used whenever the individuals need it. Semi-full availability means that a car is shared with someone else but in most of the cases it will be available when the individual needs it. This category is relevant only when level-5 automated vehicles enter in the fleet. Partial availability means that a car is shared with someone else and could not always be available. No availability means that there is not a car to use as a driver: individuals belonging to this category can travel by car as passengers.

The number of new private cars in one year is estimated as an (exogenous) fraction of the stock of vehicles in the previous year.

The composition of new cars in terms of automation level is computed using shares depending on potential supply as well as on differences of price between cars of different automation level.

Potential supply shares depend on maturity of automation technology (which includes capacity of mass-production). Maturity is modelled as a stock with an inflow depending on investment in R&D and a fixed outflow rate. The calculation is separated for cars, trucks and buses, under the assumption that the development of these three vehicle categories is independent to each other. In the reference case, investments are exogenous and correspond, by definition, to a level that does not allow to reach the level of maturity where CAD vehicles of automation level 5 (CAD-5 from now on) are produced. In the Scenario case, base investments are larger and are endogenously modified according to the comparison between supply and demand of fully automated vehicles (Automation level 5): if demand of CAD-5 vehicles tend to exceed potential supply then investments are accelerated, otherwise are smoothed. The calculation is again separated for cars, trucks and buses.

The total number of scrapped cars is computed in order to ensure that the size of the fleet is the one computed previously. The composition of scrapped cars according to the automation level depends on the composition of the fleet.

Using the shares of new cars and scrapped cars by automation level, the composition of the stock of private cars can be computed. Finally, the composition of the fleet by powertrain (ICE or innovative) is added using exogenous shares (based on ASTRA fleet).

Taxi e-car sharing fleets

Total size of Taxi e Car sharing fleets is computed from activity of these two modes and considering (exogenous) average yearly mileage. The composition of new vehicles and of the fleet is modelled in a similar fashion as for cars.

Bus fleet

Total size of bus fleet is computed from bus activity and considering (exogenous) average yearly mileage. The composition of new vehicles and of the fleet is modelled in a similar fashion as for cars.

Truck fleet

Total size of truck fleet by truck size is computed from truck activity and considering (exogenous) average yearly mileage. The composition of new vehicles and of the fleet is modelled in a similar fashion as for cars. Investments and maturity.

Vehicles purchase costs

For each vehicle category (cars, trucks, buses), base purchase costs are defined exogenously in the Reference case for each automation level. These base values are changing (decreasing) over time as effect of base investment. In the Scenario case, the base values can be modified if investments are accelerated.

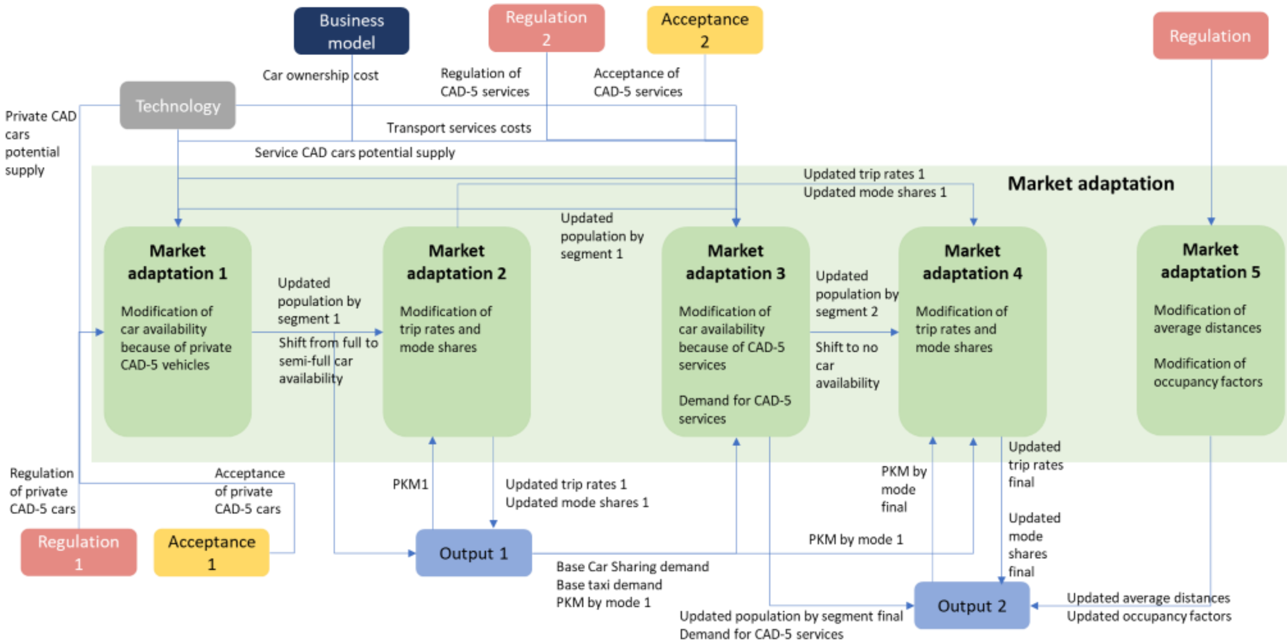
Car cost applies to private cars as well as to taxi and car sharing cars.

Car Market adaptation module

The following figure provides an overview of the Car Market adaptation module. This module manages various tasks which are interlinked and are linked to other modules. So, the description of the module is based on five different sub-modules:

- Market Adaptation 1: first adaptation of car availability in population because of private CAD-5 cars;
- Market Adaptation 2: first modification of trip rates and mode shares because of private CAD-5 cars;
- Market adaptation 3: final adaptation of car availability in population considering also CAD-5 services and computation of demand for CAD-5 services;
- Market Adaptation 4: final modification of trip rates and mode shares considering also CAD-5 services;
- Market Adaptation 5: modification of average distances and occupancy factors.

Figure B.3 The car market adaption module



Market adaptation 1

In the first sub-module of Market Adaptation, it is computed how population by car availability changes as effect of private CAD-5 cars:

- Assumption 1: when CAD-5 cars are available, some households where there are more members with a driving license and more cars can decide to give up one car (or more cars) as a CAD-5 cars can be shared;
- Assumption 2: when CAD-5 cars are available, groups of individuals not owning a car can decide to jointly purchase a CAD-5 car and share it. Also, individuals unable to drive (e.g. elderly people) can purchase a CAD-5 car.

This sub-module translates these two assumptions into a shift of individuals from full car availability to semi-full (assumption 1) from no availability to partial availability (assumption 2) and from no availability to full availability (assumption 3).

The key factors for these adaptations are:

- regulation of private CAD-5 cars: if they can travel without nobody onboard and repositioning themselves there are many more possibilities that the same car is used by different individuals. Also, if individuals not holding a driving license are allowed to own a level 5 automated cars, car ownership will likely increases. This element is modelled in the Regulation module;

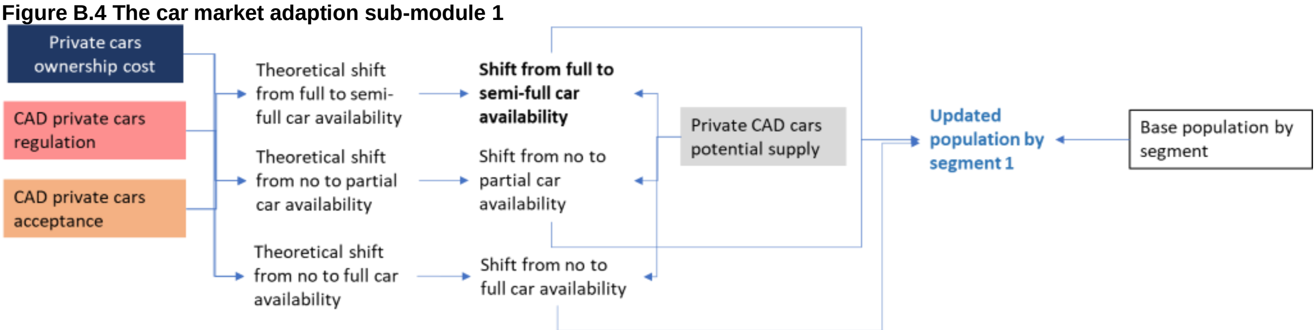
- Ownership cost of CAD-5 cars (in comparison to ownership cost of conventional cars). These costs are computed in the Business model module;
- Acceptance of fully autonomous vehicles: if people do not trust or like them they won't be purchased. This aspect is modelled in the Acceptance module.

Then, also other elements play a role, e.g. individuals can share the same car only if the timing of their trips is compatible. These elements are incorporated in the exogenous base shifts.

Furthermore, the shift can happen only until there are enough CAD-5 cars from supply, which is provided endogenously by the Technology module.

The following figure shows the structure of the sub-model.

Figure B.4 The car market adaption sub-module 1



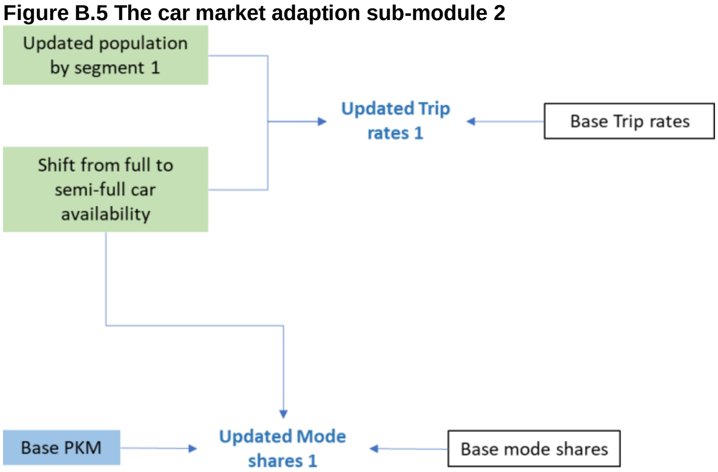
Market adaptation 2

In the second sub-module of Market Adaptation, it is computed how base values of trip rates and mode shares change as effect of the population shift computed in the first sub-module.

The assumptions are:

- Those who shift from Full car to Semi-full car do not change their mobility habits and continue to make the same number of trips and to use car for the same share of trips;
- Those who shift from No car to either Partial or Full car take advantage of the availability of car and assume the mobility habits of those with that level of car availability in terms of number of trips made and share of trips made by car.

Figure B.5 The car market adaption sub-module 2

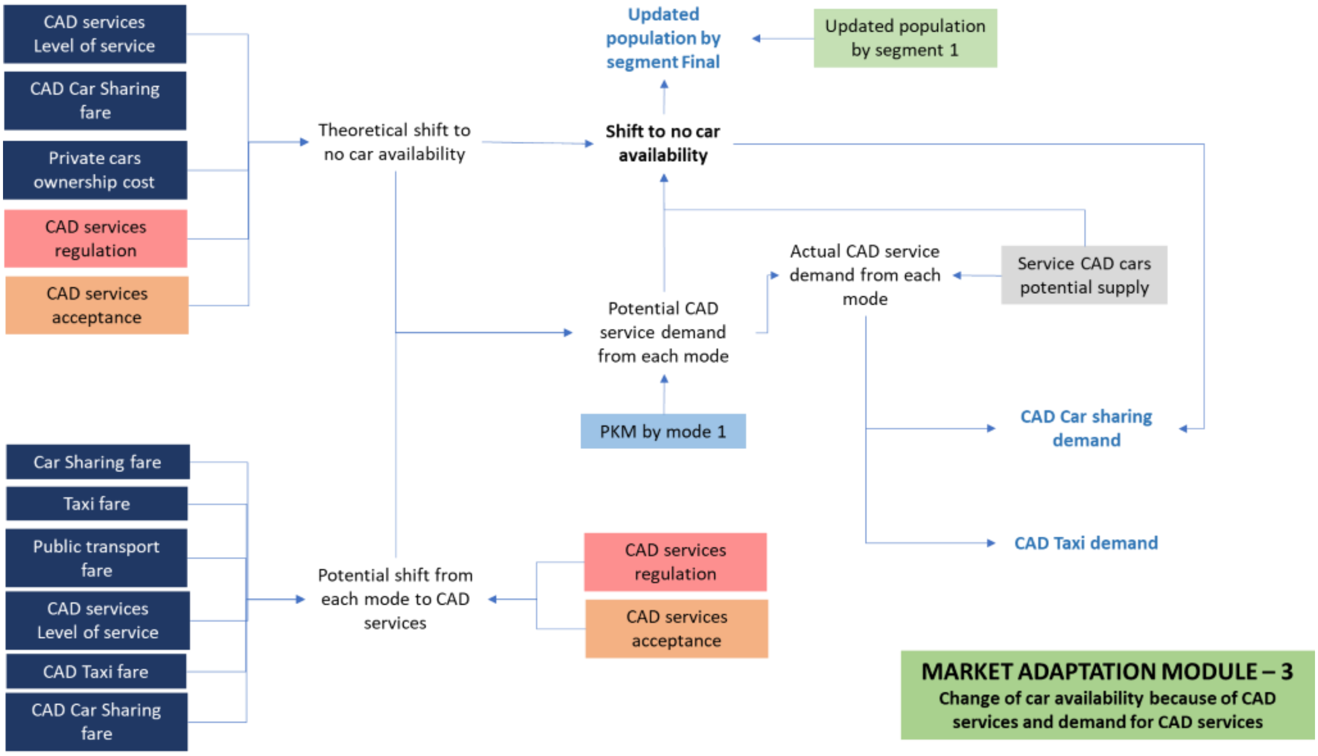


Market adaptation 3

In the third sub-module of Market Adaptation, there are three main calculations:

1. How population by car availability changes as effect of transport services made with CAD-5 cars;
2. How much demand from each mode could potentially shift to CAD-5 services;
3. How large the overall potential demand for CAD-5 services is.

Figure B.6 The car market adaption sub-module 3



Potential shift of population towards no car availability

Assumptions:

- If services with CAD-5 services (RoboTaxi and Ride-sharing) are available (because of technology and regulation), individuals compare the cost of owning and using own car against using CAD-5 services. If the latter is more convenient, own car is dropped and individuals shift to No car availability;
- The feasibility of the shift takes into account that CAD-5 services may exist only locally while own car can be used also for long distance trips;
- The convenience of the shift takes into account the level of CAD-5 services: the more vehicles are available the easier to use the service is and so the stronger the propensity to give up own car is;
- Acceptance of CAD-5 services (which is different from acceptance of private CAD-5 cars) also plays a role.

Potential demand for CAD-5 services from car

Potential demand from car is made of two components.

One component is the share of Car pkm equivalent to the share of individuals who would shift from some level of car availability to no car availability.

The second component is a share of pkm that in the base case are made by car by those who have semi-full or partial car availability. This share depends on the fare of CAD-5 services, their level of service, personal regulation (who can use CAD-5 services) and acceptance.

Potential demand for CAD-5 services from non-car modes

Demand from traditional **car-sharing** services depends on four elements: cost of the services (traditional vs CAD-5), level of service, personal regulation (i.e. who can use CAD-5 services, specifically whether CAD-5 services can be used by everyone or only by e.g. people in age), acceptance.

Public transport fare can be higher or lower than the fare of CAD-5 services. Unless difference is huge, some public transport users could be willing to shift (especially among higher income) even paying more, while other public transport users could prefer to stick on their choice even if cost is higher.

Slow modes[50] do not pay fare, so the fare effect exists and is based only on the level of fare of CAD-5 services. The share of demand for slow modes that would shift to CAD-5 services should be zero unless fare is limited and even for fare = 0, shift should be significantly < 1.

It is supposed that CAD-5 services operated by car will not be developed for trips for which train and air are used, so no modal shift from these two modes is expected.

Total Potential supply for RoboTaxi and Ride-Sharing

Total potential supply for RoboTaxi and Ride-Sharing depends on the potential number of CAD-5 cars in the fleet of car-sharing and taxi (based on estimations computed in the Technology module, see section 0), the yearly mileage and the occupancy factor.

Final update of population by segment

Results of this sub-module allow to revise the adaptation of population according to car availability made in Market adaptation 1.

Market adaptation 4

In the fourth sub-module of Market Adaptation, it is computed how base values of trip rates and mode shares further change (building on results of the second sub-module) as effect of the population shift computed in the third sub-module.

The assumption is that those who shift to No car availability do not change their mobility habits and continue to make the same number of trips. In other words, the assumption is that car owners are willing to give up a personal car only if their mobility is not limited by this choice.

Figure B.7 The car market adaption sub-module 4

Market adaptation 5

In the fifth sub-module of Market Adaptation, the modifications of average travel distances and of occupancy factors are computed.

Adapting private car travel distances

CAD-5 cars would change the distance of travels from two perspectives. On the one hand, if CAD-5 cars are allowed to move empty for repositioning, more easily the same car can be used by different individuals. For instance, consider two members of one household. One makes a commuting trip at 8 am. The other one makes a shopping trip at 10 am. A CAD-5 car could return home after the initial trip to be used by the second member of the household and then return in the evening to the workplace of the first member for her return trip. This scenario would imply that the car would run for a longer distance than the sum of the distance of two single cars used independently by the two individuals:

<u>Base case (2 individuals – 2 cars):</u>

- 8 am Onwards trip individual A: distance 20;
- 10 am Onwards trip of individual B: distance 5;
- 11 am Return trip of individual B: distance 5;
- 6 pm Return trip individual A: distance 20.

Total distance (vkm) = 50

<u>Scenario case (2 individuals – 1 CAD-5 car):</u>

- 8 am Onwards trip individual A: distance 20;
- 8:30 am Return trip of CAD-5 car empty: distance 20;
- 10 am Onwards trip of individual B: distance 5;
- 11 am Return trip of individual B: distance 5;
- 5:30 pm Trip of CAD-5 car empty to collect individual A at workplace: distance 20;
- 6 pm Return trip individual A: distance 20.

Total distance (vkm) = 90

This is just one simple case. The overall effect should consider a number of potential combinations of different numbers of individuals sharing the same car for different trips. In some of these combinations the overall distance might decrease, but it seems quite clear that in most of the cases total distance increases when a CAD-5 car is used. Therefore, this effect is considered by an additive term > 0. The definition of the base value of this additive term will be a matter of testing (this parameter could be a typical candidate for sensitivity analysis).

On the other hand, CAD-5 private cars can affect average distances because time spent travelling by car can become less important and individuals might choose to move to rural areas to enjoy a better living environment, even if this would mean being more far away job, services, etc. Again, the size of this effect is hard to quantify; by now it is implemented by means of another additive term whose value is to be defined.

The effect on total average distance depends on the share of CAD-5 cars in the fleet:

The incentive to move outside cities has also consequences on the split of activity between rural and urban environment. When distances grow also the share of activity in rural areas grows. To keep the consistency between the changes of total distance, the modification of the share of urban activity is computed.

Adapting CAD car sharing travel distances

Car sharing services operated by fully autonomous cars would be different from conventional services because repositioning would be more frequent (as cars could be relocate themselves if this is allowed). This aspect is taken into account by an additive factor which is an inverse function of the number of CAD-5 car sharing cars compared to the current number of conventional car sharing cars: only if the number of CAD-5 car sharing cars is significantly higher than the current number of car sharing cars, this compensate the more frequent repositioning and so the effect is neutral. If the number of CAD-5 car sharing cars is even larger, than the need for repositioning is reduced and so distances.

Furthermore, routes could be adjusted to pick-up and drop passengers. So for some of them routes will be longer than using conventional car sharing. Again, this depends on the number of CAD-5 car sharing cars: the more cars are available and the less adjustment of routes is needed (but also the average occupancy factor is reduced, see below).

Adapting private car occupancy factor

Autonomous repositioning of private CAD-5 cars means that a certain share of activity will be with occupancy factor = 0. There will also be more car-pooling but on average it is more likely that occupancy factor is reduced. Again, it is very difficult to estimate the size of this effect and again there is a role for regulation (can CAD-5 cars circulate without any passengers? And where?).

Adapting Car sharing occupancy factor

Autonomous repositioning of CAD-5 car sharing cars means that a certain share of activity will be with occupancy factor = 0. With a limited number of CAD-5 cars the need for repositioning will be higher. With many CAD-5 cars, the need for repositioning could be even lower than today and so the occupancy factor could even slightly grow.

On the other hand, as the number of CAD-5 car sharing cars grows there are more chances that car is shared along the route and so the occupancy factor should also grow.

Bus Market adaptation module

The Bus Market adaptation module deals with the shift of demand towards RoboBus when they are available. The module uses results from the Technology module and from the Business model module. The approach is the same used to estimate shift towards RoboTaxi and Ride-Sharing. The following assumptions are made:

- For local demand, RoboBus is considered an alternative for those that in the Reference case travel by public transport, bike or walk. Car, taxi and Car sharing users are supposed to be not interested in RoboBus as they can choose RoboTaxi or Ride-Sharing;
- For long distance demand, RoboBus is considered an alternative for those that in the Reference case travel by train. Air users are supposed to be not interested in RoboBus because of lower speed compared to air services.

Potential demand for RoboBus

Potential demand from bus users

One portion of potential demand for RoboBus come from bus users in the Reference case. This portion depends on four elements: cost of the services (traditional bus vs RoboBus), level of service (i.e. where RoboBus services exist and how frequent they are; this aspect is dealt with endogenously in the Business model module), spatial regulation (where RoboBus services can circulate; this aspect is dealt with endogenously in the Regulation module). Two separate components are considered: public transport users and users of private coach services.

Potential demand from slow modes
One portion of potential demand for RoboBus comes from pedestrian and bike users in the Reference case. Those users do not pay fares in the reference scenario, so the fare effect exists and is based only on the level of fare of RoboBus services.

Potential demand from train
One portion of potential demand for RoboBus comes from train users in the Reference case. RoboBus compete with train only on medium-long distance trips, therefore, only private transport RoboBus can attract demand from train users. Furthermore, it is supposed that RoboBus will always be slower than trains and that business travellers will always prefer the fastest alternative. Therefore, the shift from train to RoboBus can occur only for non-business long trips.

Potential supply for RoboBus
Total potential supply for RoboBus depends on the potential number of CAD-5 buses in the bus fleet (based on estimations computed in the Technology module), the yearly mileage and the occupancy factor:

Actual demand for RoboBus
The actual demand for RoboBus is just the minimum between potential demand and supply.

Truck Market adaptation module

The Truck Market adaptation module deals with the adoption of CAD-5 trucks when they are available. The module uses results from the Technology module and from the Business model module. The approach is different from that used for other modes. Here the final outcome is the share of CAD-5 trucks in the fleet rather than the demanded activity. The rationale is that we are interested in estimating the effect of automation on the overall truck activity rather than on the share of truck activity performed with CAD-5 vehicles.

Automation is expected to reduce the cost of road freight transport and so market share of this mode of transport can grow, by subtracting demand from other modes (mainly rail, probably IWW in some countries). So, we need first of all to estimate how much road freight transport costs would change and this depends on the adoption of CAD-5 trucks. On the one hand, the penetration of different levels of automation in the truck fleet depends on the development of technology and this is modelled in the Technology module. Here, the elements related to costs, acceptance and regulation are accounted for when CAD-5 vehicles are involved.

Demand for CAD-5 trucks
The starting point is the potential share of CAD-5 trucks according to maturity of technology. This potential share is computed in the Technology model. This share can be modified as effect of costs, regulation and acceptance.

Average road freight transport cost by transport type
Road freight transport rates for each transport type (International, National, Regional, Local) are computed considering the operating cost for each vehicle type (computed in the Business Model

module, see section 0), the use of different types of trucks for each transport type (defined in the Output module, see section 0) and the fleet composition.

Road freight transport demand change

As effect of the introduction of autonomous trucks, the cost of road freight transport in the scenario case will change compared to the reference case. It is assumed that if the cost decreases there will be more demand for road freight transport, while if the cost increases there will be less demand.

The cost of road freight transport is assumed to change because of two effects. On the one hand, operating costs of CAD-5 trucks are different (as shown in the Business Model module). On the other hand, already lower automation levels will allow the platooning of trucks, which is expected to reduce costs because of smoother driving and other elements.

The effect of platooning is considered computing the share of trucks with automation level 3 or above available for each transport type.

Business model module

This module deals with:

- costs for owning private cars;
- costs for using transport services;
- level of service of CAD-5 services.

Ownership cost of private cars

Ownership cost of private cars are direct costs for car owners. External costs are not accounted for unless they are incorporated in taxation (e.g. in tolls).

Ownership car costs includes the following fixed costs:

- Purchase cost (amortisation);
- Registration taxes;
- Insurance;
- Parking costs when car is at home.

And the following variable costs:

- Energy cost;
- Maintenance cost;
- Parking costs when car is used;
- Tolls.

Fixed costs

(Yearly) Purchase cost is computed in the Technology module for each car type.

Registration taxes are defined in the Regulation module for each car type (different levels are assumed to represent countries with lower taxes and countries with higher taxes).

Insurance costs are supposed to be market-driven costs influenced by the number of accidents. If accidents are reduced, insurance costs decrease. Furthermore, it is supposed that insurance are sensitive to the contribution of automation to safety. One assumption is that until there are only few vehicles with Automation level >3, the confidence of their safety level is limited and so insurance companies will ask to pay more than for a conventional vehicle. As the number of highly autonomous vehicles increases, the evidence of their safety will emerge (it can be only so: should autonomous vehicles reveal to be unsafe, they will never be accepted) and insurance cost will be reduced below the level of insurance for other vehicle types.

Parking cost at home is borne by those who do not own a private space and need to rent a place in a private garage or to pay for parking on street in regulated areas (at least in Italy, residents can use regulated parking by paying a yearly fee).

Variable costs

Energy cost (per vkm) is an exogenous value for each car type.

Maintenance cost (per vkm) is an exogenous value for each car type.

Parking cost (per trip) when car is used depends on parking fares (in Euro/h) and on the share of trips for which car is parked in a regulated area. Both these elements are defined in the Regulation module. A further element is the average duration of parking, which is an exogenous element different by population group and trip purpose. The yearly parking cost during trip is the sum over the yearly trips and cost per vkm is obtained by dividing yearly cost by average yearly mileage.

Tolls costs depend on the car activity on tolled network and on the value of the toll. The main elements are defined in the Regulation module.

The module provides overall ownership cost by car segment (powertrain and automation level).

Cost of passenger transport services

Cost of taxi services is assumed to be a result of production costs (which are supposed to include also a normal profit rate for the operator). In scenarios, Taxi fare is recomputed considering the modification of taxi fleet composition and also the modification of the utilisation rate of the vehicles (the assumption is that if demand changes, there is an adaptation of the utilisation rate before that the size of the fleet changes and if e.g. taxi travel less fare is raised to somewhat compensate the reduction of activity).

Cost of RoboTaxi services (i.e. services operated with cars with automation level 5 without driver) are computed with the same equations used for conventional taxi, with the main difference that driver costs are zero.

Like for taxi, cost of car sharing services is assumed to be a result of production costs (which are supposed to include also a normal profit rate for the operator). In comparison to taxi, there are no driver costs but there are repositioning costs, which in the reference case are an exogenous value. In scenarios, Car Sharing fare is recomputed considering the modification of fleet composition and also the modification of the repositioning cost and of the utilisation rate of the vehicles. Cost of Ride-sharing services (i.e. services operated by cars with automation level 5 without driver) are computed with the same equations used for conventional car-sharing, with the main difference that repositioning costs are zero.

Two different costs of bus are computed: one for bus as public transport (local trips) and one for bus as private service (long distance trips). **Public transport** bus cost is assumed to be a result of production costs and of a certain level of subsidies. **Private transport** bus cost is assumed to be a result of production costs (which are supposed to include also a normal profit rate for the operator), without any subsidy and according to a normal utilisation rate of vehicles.

Also, for RoboBus, two different costs of bus are computed: one for bus as public transport (local trips) and one for bus as private service (long distance trips). For **public transport** RoboBus, costs do not include the cost of drivers but do include the costs for the management of the CAD-5 bus fleet: it is assumed that the management of a fleet of fully autonomous buses requires a dedicated structure (hardware, software, personnel). It is also assumed that the cost for this structure is borne by transport service operators (while it is assumed that infrastructural investments as well as overall traffic management are provided by the public sector). Subsidies for public transport operated by CAD-5 vehicles are represented by a specific variable as the policy makers might decide to differentiate subsidies or even to not subsidise services operated with CAD-5 vehicles. Subsidies are managed in the Regulation module (see section 0).

For **private transport** RoboBus, costs do not include subsidies but include tolls.

Cost of trucks

Cost of trucks is assumed to be a result of production costs (which are supposed to include also a normal profit rate for the operator). In scenarios, the calculation of truck cost includes the cost of the management of the CAD fleet.

Level of service of CAD-5 services

Level of service of Robotaxi, Ride-Sharing and RoboBus considers two aspects.

First: where the services are available. Services might be available only in (some) urban areas for local trips or can be available also for interurban trips but maybe only between some large cities, etc. This aspect is represented by a share (a value between 0 and 1 exogenously defined) which is interpreted as the share of car mobility for which users might use a Robotaxi or Ride-Sharing. This share is influences by regulation (i.e. where CAD-5 services can circulate).

Second aspect is how easy accessing Robotaxi, Ride-Sharing and RoboBus is. If these services are operated only with a few vehicles, it can be difficult to book a ride and/or routes implying large detours. So, attractiveness of these services is low. This aspect is considered on the basis of the ratio between CAD-5 vehicles in the Taxi, Car-Sharing and bus fleets and the total number of private cars and buses.

Private car yearly mileages

The average private car yearly mileage depends on yearly mileage of different population groups and on car ownership. The yearly mileage of different population groups is obtained considering their travel activity made by car. The average private car yearly mileage for each automation level is based on exogenous assumption regarding the different usage of each level. The assumption – consistent with the adjustment of average travel distances made in the Adaptation module – is that cars with highest automation levels are used more.

Regulation module

The regulation module deals with:

- Regulation of private CAD vehicles;
- Regulation of CAD service vehicles;
- Regulation of trucks;
- Registration taxes;
- Road charging;
- Parking fares;

- Public transport subsidies;
- Investments for IT on the infrastructure side.

Regulation of private CAD vehicles

Regulation of private CAD vehicles consists of rules about:

- Where private CAD vehicles can circulate (spatial regulation);
- Who can travel on private CAD vehicles (personal regulation);
- Whether private CAD vehicles can make empty trips or not (relocation regulation).

Spatial regulation

Regarding where private CAD vehicles can circulate, at the aggregated level of detail of the model, only general circumstances can be identified:

- Whether CAD private vehicles can circulate in urban areas or partially or not at all;
- Whether CAD private vehicles can circulate in rural areas or not.

The combinations of these general circumstances generate six conditions. For each condition, a spatial regulation index is defined in the interval 0 – 1. 0 means strictest regulation (private CAD vehicles cannot circulate); 1 means no regulation (private CAD vehicle can circulate without spatial limitations). The values of these indexes are exogenous and of course can change over time.

Personal regulation

Regarding who can travel on private CAD vehicles there are three main general circumstances:

- CAD private vehicles can be used only by individuals with a driving license;
- CAD private vehicles can be used by all individuals in age with or without a driving license;
- CAD private vehicles can be used by everyone.

For each circumstance a personal regulation index is defined in the interval 0 – 1. The values of these indexes are exogenous and of course can change over time.

Relocation regulation

Regarding empty trips of private CAD vehicles there are only two alternatives: allowed or not. Regulation can be different in urban areas and rural areas. For each circumstance a relocation regulation index is defined in the interval 0 – 1 The values of these indexes are exogenous and of course can change over time.

Regulation of CAD services vehicles

Regulation of CAD service vehicles (RoboTaxi, Ride-Sharing and RoboBus) consists of the same rules concerning private CAD vehicles: spatial regulation, personal regulation and relocation regulation. Specific parameters, diverse from those used for private cars are used because rules can actually be diverse. The general circumstances are the same as for private CAD vehicles with the exception of empty trips, which for CAD services vehicles could be allowed only during night.

Regulation of CAD Trucks

Regulation of CAD trucks is basically only spatial regulation. I.e. where CAD-5 trucks can circulate. As for passenger modes, the two general circumstances can be identified:

- Whether CAD-5 trucks can circulate in urban areas or partially or not at all;
- Whether CAD-5 trucks can circulate in rural areas or not.

Registration taxes

Registration taxes are one component of car ownership costs. They are a matter of regulation as authorities can use this leverage to incentive or penalise some vehicle type (e.g. electric cars). Values are defined exogenously for each year.

Road charging

In the Regulation module two elements are (exogenously) defined:

- The share of activity incurring in road charging;
- The value of charge.

The share of car activity incurring in road charging depends on trip purpose because for each trip purpose there is a different probability of travelling on charged roads. At the same time, this probability changes when road charging is more or less extended. For instance, if tolls exist only on motorways, the share of rural car activity for commuting trips paying tolls is lower than the share of rural car activity for long distance trips; if tolls are applied on other roads both shares grow but differently.

The share of truck activity incurring in road charging depends on Freight transport type, because e.g. international transport uses the main network more than regional transport.

The share of bus activity incurring in road charging is defined only for private coach services as it assumed that public buses never use tolled road (or in case are exempted).

Parking fares

In the Regulation module parking fares are modelled similarly to road charging by means of two elements exogenously defined:

- The share of car trips subjected to charged parking;
- The value of parking fares.

The share of car trips subjected to charged parking depends on trip purpose but also on population group.

Two values of parking fares are defined. One is a cost per hour for parking when making a trip, the other is a yearly cost that residents need to pay for parking their car in regulated spaces on streets. Both costs depend on zone type (can be zero in rural areas).

Public transport subsidies

Public transport subsidies are exogenous elements in the reference case and, for conventional bus, also in the scenario case.

Subsidies for RoboBus are computed endogenously in the scenario case. It can be assumed that the same base level of subsidies of buses is applied or a different one (or no subsidies at all). Also, it can be represented the possibility that base subsidy value is adjusted to consider that Robobus operators do not hold drivers costs, but hold a cost for managing the fleet of autonomous buses.

IT investment on road infrastructure

The assumption is that some features of CAD vehicles work if there is communication between the vehicle and the infrastructure. Another assumption is that the IT required on the infrastructure side to communicate with vehicles is developed only if there is public investment.

The share of infrastructure equipped with IT is a stock fed with a yearly flow. The yearly flow depends on yearly investments. Yearly investment are defined exogenously in term of an index and a linear relationship transform the index of investment into the yearly additional share of infrastructure equipped (the coefficient of the linear relationship will be a matter of calibration/sensitivity.

Acceptance module

In the Acceptance Module, the level of acceptance for CAD-5 vehicles is computed. The acceptance is computed separately for each type of vehicle (private car, RoboTaxi, Ride Sharing, RoboBus, truck). It is an exogenous base value (whose trend will be a matter of assumption/calibration/sensitivity analysis) modified as effect of accidents and congestion.

Output module

In the output model transport activity is computed as well as their effects in terms of accidents and congestion.

Passenger transport activity

Passenger transport activity is computed first in terms of trips using population and trip rates. Then average distances are used to compute pkm and mode shares are applied to compute demand by mode. Finally, occupancy factors are used to compute vkm by mode (only for private cars, taxi and car sharing).

Mode shares are exogenous values changing over time according to the EU Reference Scenario 2016 (translated into the more aggregated and prototypical structure of the model).

The following main indicators are computed:

- Total pkm activity by mode;
- Pkm mode and zone type (urban and rural) (only for road modes);
- Total vkm activity by mode and zone type (urban and rural) (only for road modes);
- Total vkm activity by zone type and automation level (only for road modes).

Freight transport activity

Freight transport activity is exogenous in terms of tonnes originated. Then average distances are used to compute tkm and road mode shares are applied to compute demand by truck. Load factors are used to compute vkm.

The following main indicators are computed:

- Tkm by freight transport type and truck type;
- Tkm by freight transport type, truck type and zone type (urban and rural);
- Vkm by freight transport type, truck type and zone type (urban and rural);
- Vkm by automation level and zone type (urban and rural).

Accidents

Accidents are computed as result of activity and accident rate by automation level.

Accident rates for level of automation 0 are exogenously defined. For the other automation levels, accident rates are improvements of those for level 0 as effect of vehicle technology and infrastructure technology.

In the scenario case another element is accounted for: the mix of autonomous and non-autonomous vehicles. The assumption is that very few CAD-5 vehicles would not change the level of accidentality; when their share starts to grow, the mix between human-driven and autonomous vehicles might generate some problem and so increase the number of accidents; after a certain share, as the number of CAD-5 vehicles grows, traffic becomes more homogenous and this has a positive effect on accidentality.

Accidents are computed separately for private cars, taxi, car sharing, bus and truck.

Congestion

Congestion is computed in form of an index which is basically a ratio between the vkm in a given year and in the previous year.

In the scenario case, the index is also influenced by the mix of human-driven and fully autonomous vehicles (and so by the share of network where CAD-5 vehicles can operate). As for accidents, the most likely assumption is that the effect of mix is negligible as long as the share of CAD-5 is very low, when their share starts to grow, the mix between human-driven and autonomous vehicles might generate some problem and so increase the level of congestion; after a certain share, as the number of CAD-5 vehicles grows, traffic becomes more homogenous and this has a positive effect on congestion.

Detailed scenario results

Car fleet

Reference Scenario

Figure B.8 Reference Scenario – Composition of car fleet by automation level (EU27)

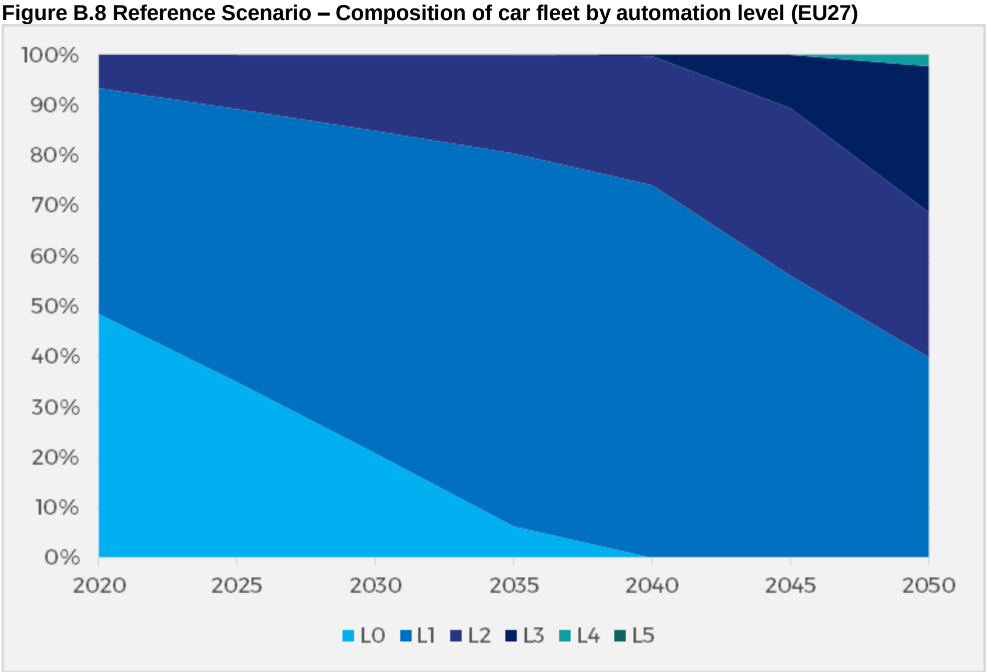


Table B.1 Reference Scenario – Composition of car fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	48%	35%	21%	6%	0%	0%	0%
L1	45%	54%	64%	74%	74%	56%	40%
L2	7%	11%	15%	20%	26%	33%	29%
L3	0%	0%	0%	0%	0%	11%	29%
L4	0%	0%	0%	0%	0%	0%	2%
L5	0%	0%	0%	0%	0%	0%	0%

Scenario 1

Figure B.9 Scenario 1 – Composition of car fleet by automation level (EU27)

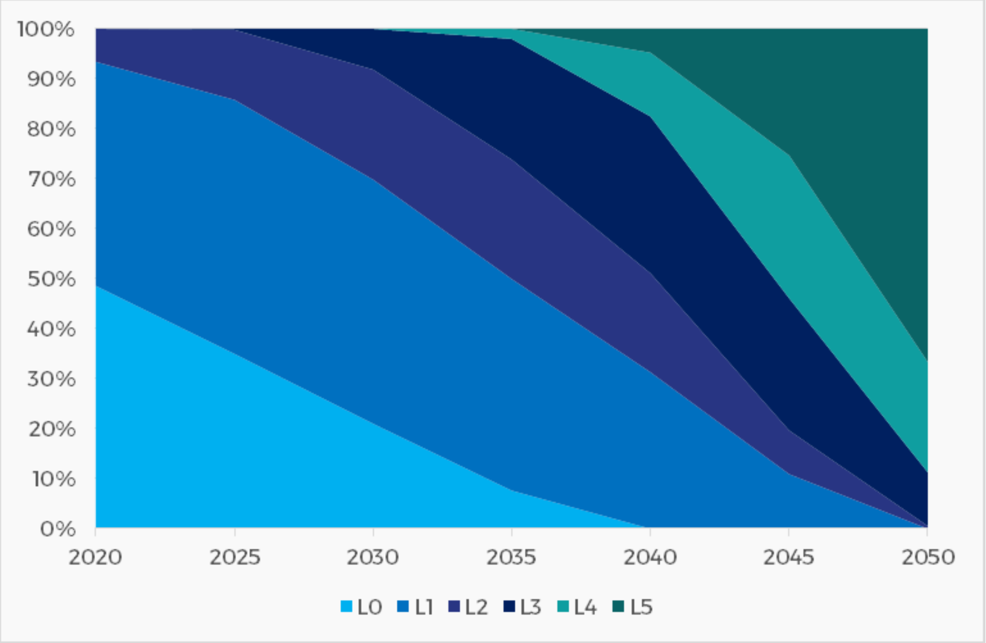


Table B.2 Scenario 1 – Composition of car fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	49%	35%	21%	8%	0%	0%	0%
L1	45%	51%	49%	42%	31%	11%	0%
L2	7%	14%	22%	24%	20%	9%	1%
L3	0%	0%	8%	24%	31%	26%	11%
L4	0%	0%	0%	2%	13%	29%	22%
L5	0%	0%	0%	0%	5%	25%	67%

Scenario 2

Figure B.10 Scenario 2 – Composition of car fleet by automation level (EU27)

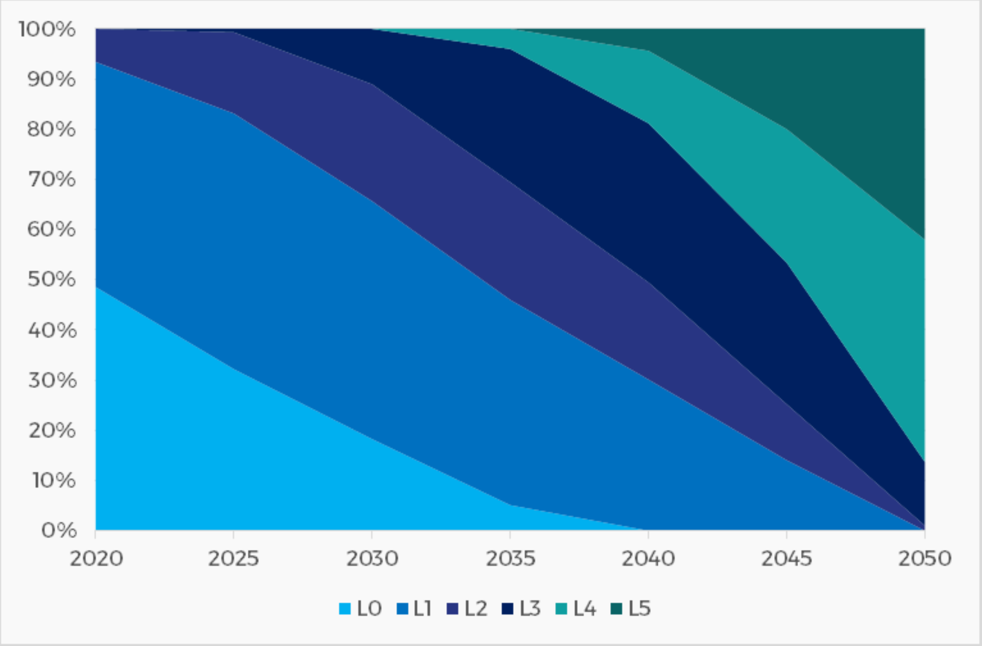


Table B.3 Scenario 2 – Composition of car fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	49%	32%	18%	5%	0%	0%	0%
L1	45%	51%	47%	41%	30%	14%	0%
L2	7%	16%	23%	23%	19%	11%	1%
L3	0%	1%	11%	27%	32%	28%	13%
L4	0%	0%	0%	4%	14%	27%	44%
L5	0%	0%	0%	0%	4%	20%	42%

Scenario 3

Figure B.11 Scenario 3 – Composition of car fleet by automation level (EU27)

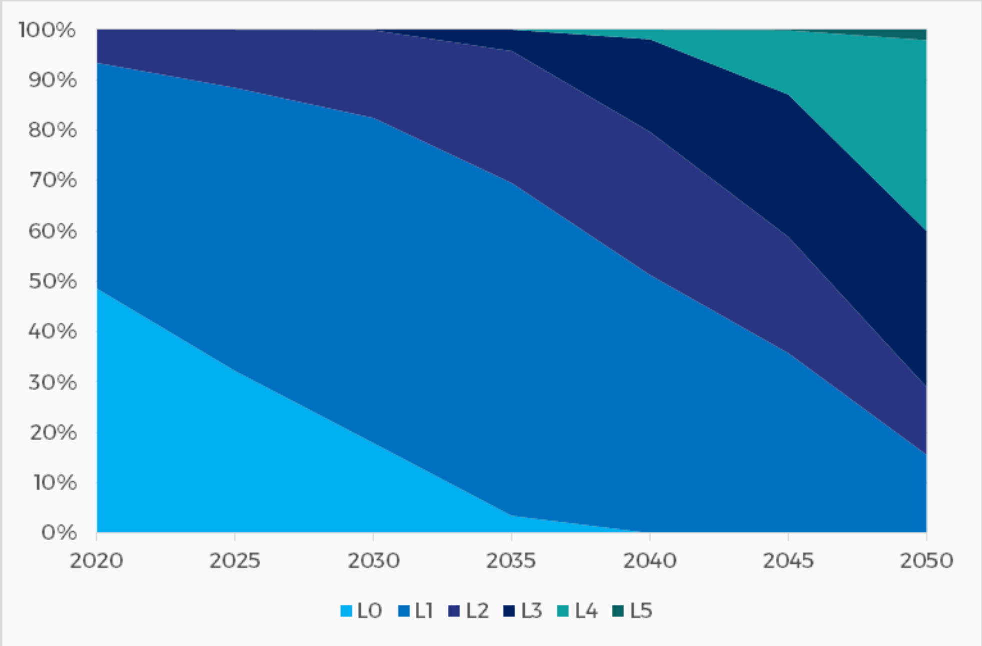


Table B.4 Scenario 3 – Composition of car fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	49%	32%	18%	3%	0%	0%	0%
L1	45%	56%	65%	66%	51%	36%	16%
L2	7%	12%	17%	26%	28%	23%	13%
L3	0%	0%	0%	4%	18%	28%	31%
L4	0%	0%	0%	0%	2%	13%	38%
L5	0%	0%	0%	0%	0%	0%	2%

Scenario 4

Figure B.12 Scenario 4 – Composition of car fleet by automation level (EU27)

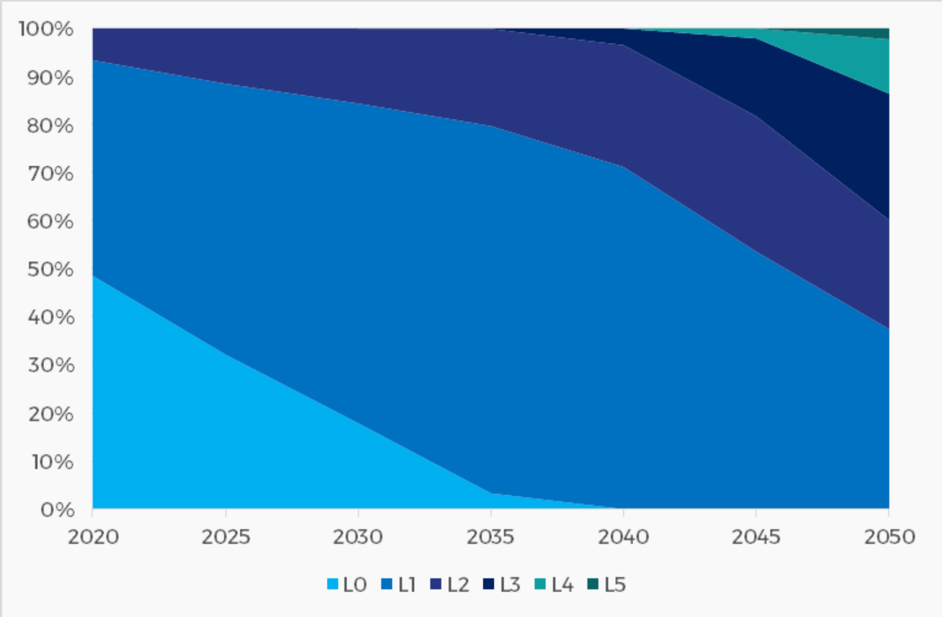


Table B.5 Scenario 4 – Composition of car fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	49%	32%	18%	3%	0%	0%	0%
L1	45%	56%	67%	76%	71%	54%	37%
L2	7%	11%	16%	20%	25%	28%	23%
L3	0%	0%	0%	0%	3%	16%	26%
L4	0%	0%	0%	0%	0%	2%	11%
L5	0%	0%	0%	0%	0%	0%	2%

Bus fleet

Reference Scenario

Figure B.13 Reference Scenario – Composition of bus fleet by automation level (EU27)

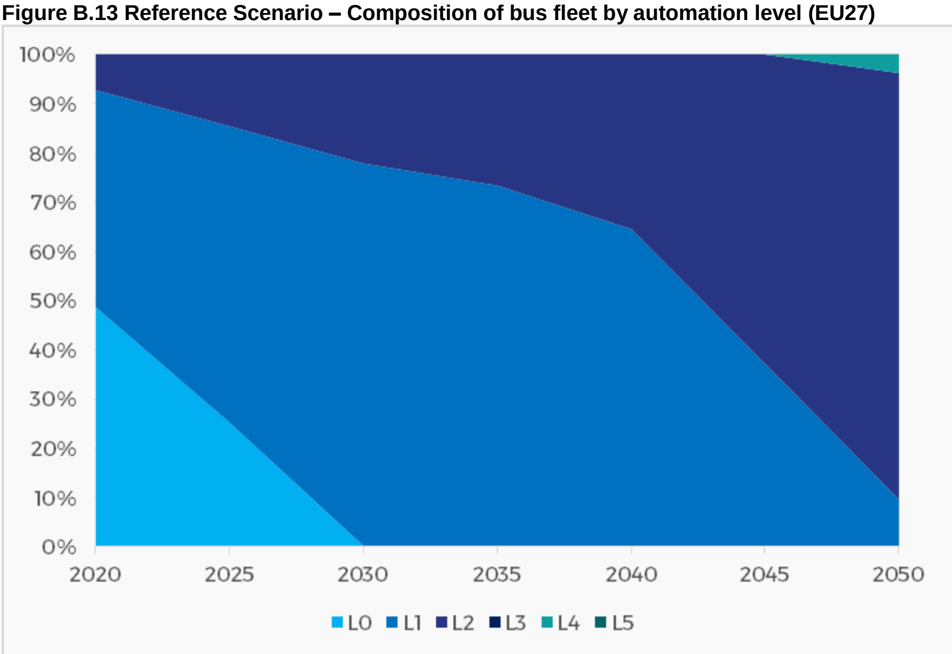


Table B.6 Reference Scenario – Composition of bus fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	49%	25%	0%	0%	0%	0%	0%
L1	44%	60%	78%	73%	65%	37%	10%
L2	7%	15%	22%	27%	35%	63%	87%
L3	0%	0%	0%	0%	0%	0%	0%
L4	0%	0%	0%	0%	0%	0%	4%
L5	0%	0%	0%	0%	0%	0%	0%

Scenario 1

Figure B.14 Scenario 1 – Composition of bus fleet by automation level (EU27)

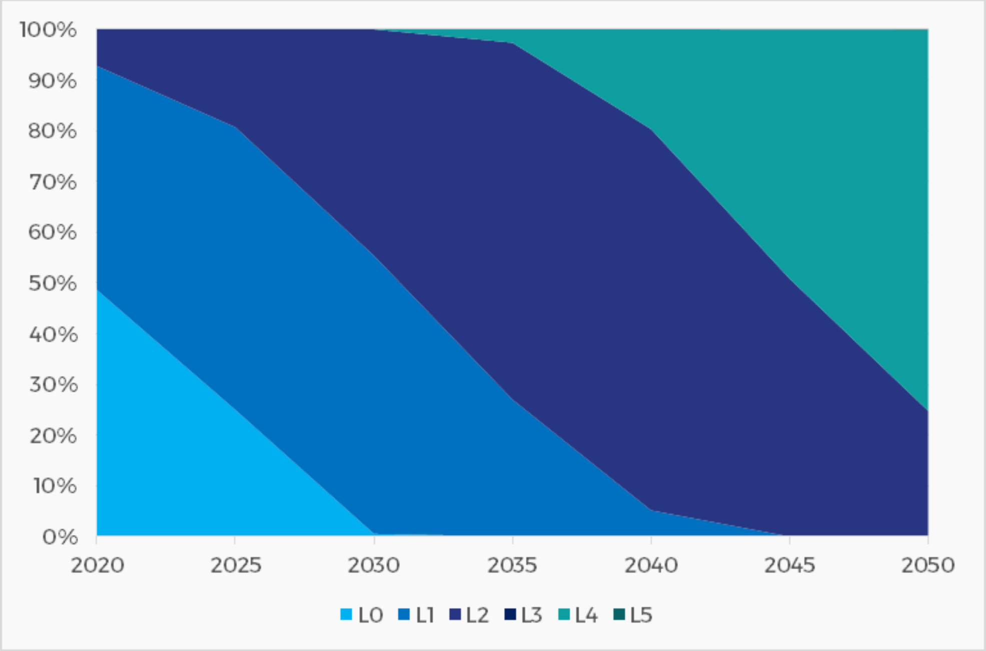


Table B.7 Scenario 1 – Composition of bus fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	49%	25%	1%	0%	0%	0%	0%
L1	44%	56%	55%	27%	5%	0%	0%
L2	7%	19%	45%	70%	75%	51%	25%
L3	0%	0%	0%	0%	0%	0%	0%
L4	0%	0%	0%	3%	20%	49%	75%
L5	0%	0%	0%	0%	0%	0%	0%

Scenario 2

Figure B.15 Scenario 2 – Composition of bus fleet by automation level (EU27)

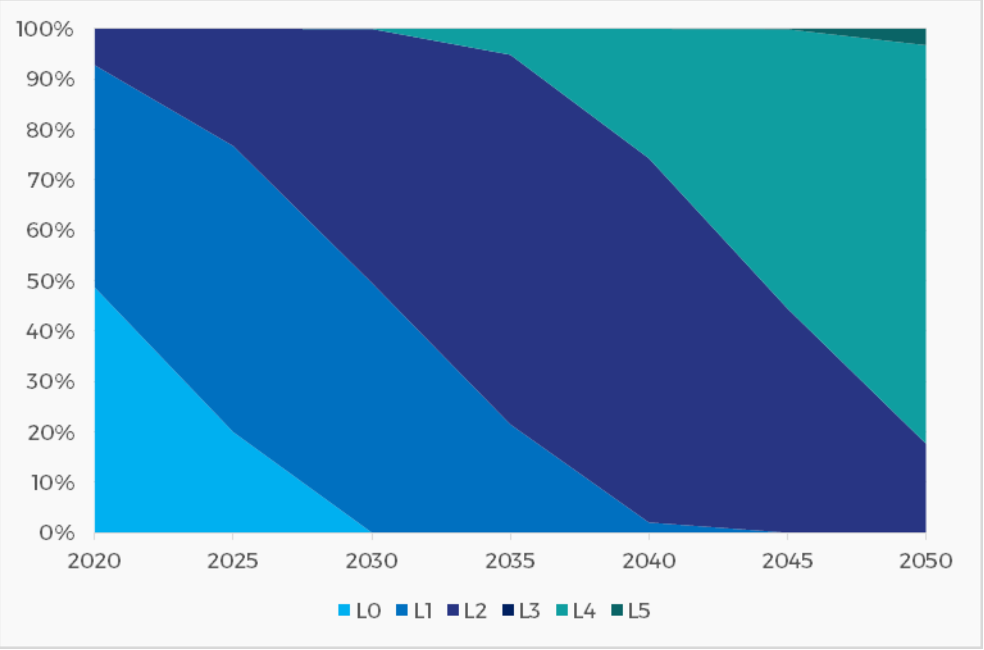


Table B.8 Scenario 2 – Composition of bus fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	49%	20%	0%	0%	0%	0%	0%
L1	44%	57%	50%	21%	2%	0%	0%
L2	7%	23%	50%	73%	72%	45%	18%
L3	0%	0%	0%	0%	0%	0%	0%
L4	0%	0%	0%	5%	26%	55%	79%
L5	0%	0%	0%	0%	0%	0%	3%

Scenario 3

Figure B.16 Scenario 3 – Composition of bus fleet by automation level (EU27)

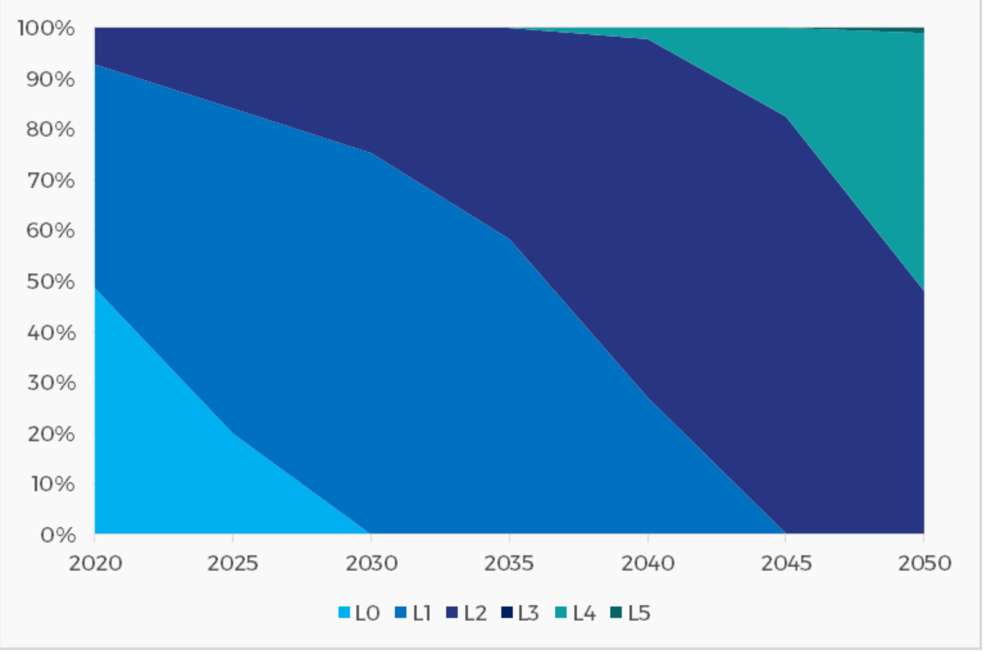


Table B.9 Scenario 3 – Composition of bus fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	49%	20%	0%	0%	0%	0%	0%
L1	44%	64%	75%	58%	27%	0%	0%
L2	7%	16%	25%	42%	71%	82%	48%
L3	0%	0%	0%	0%	0%	0%	0%
L4	0%	0%	0%	0%	2%	18%	51%
L5	0%	0%	0%	0%	0%	0%	1%

Scenario 4

Figure B.17 Scenario 4 – Composition of bus fleet by automation level (EU27)

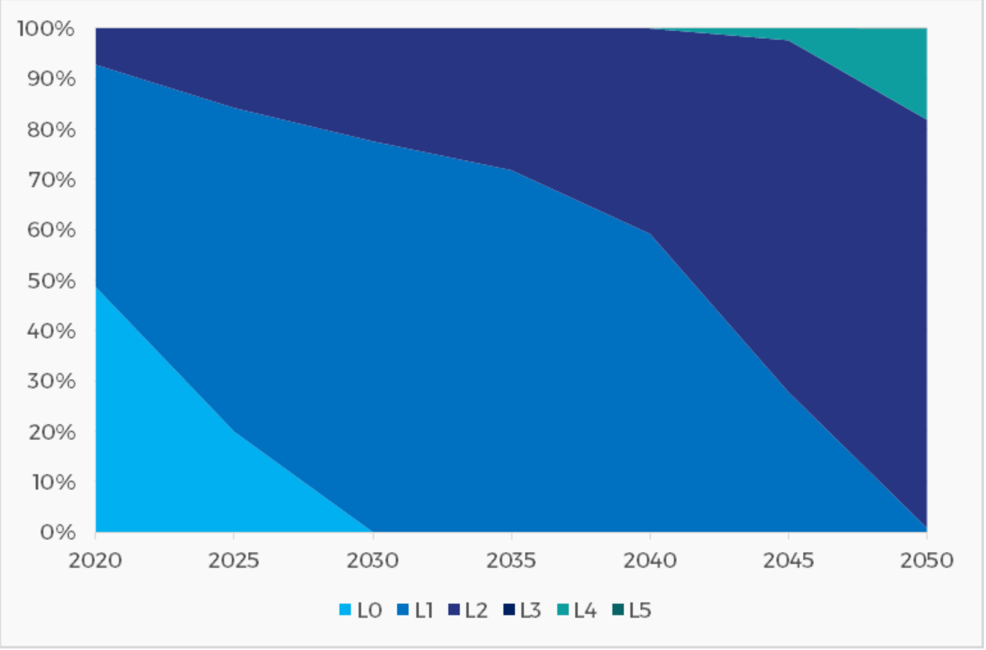


Table B.10 Scenario 4 – Composition of bus fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	49%	20%	0%	0%	0%	0%	0%
L1	44%	64%	78%	72%	59%	28%	1%
L2	7%	16%	22%	28%	41%	70%	81%
L3	0%	0%	0%	0%	0%	0%	0%
L4	0%	0%	0%	0%	0%	2%	18%
L5	0%	0%	0%	0%	0%	0%	0%

Freight vehicles fleet

Reference Scenario

Figure B.18 Reference Scenario – Composition of freight vehicles fleet by automation level (EU27)

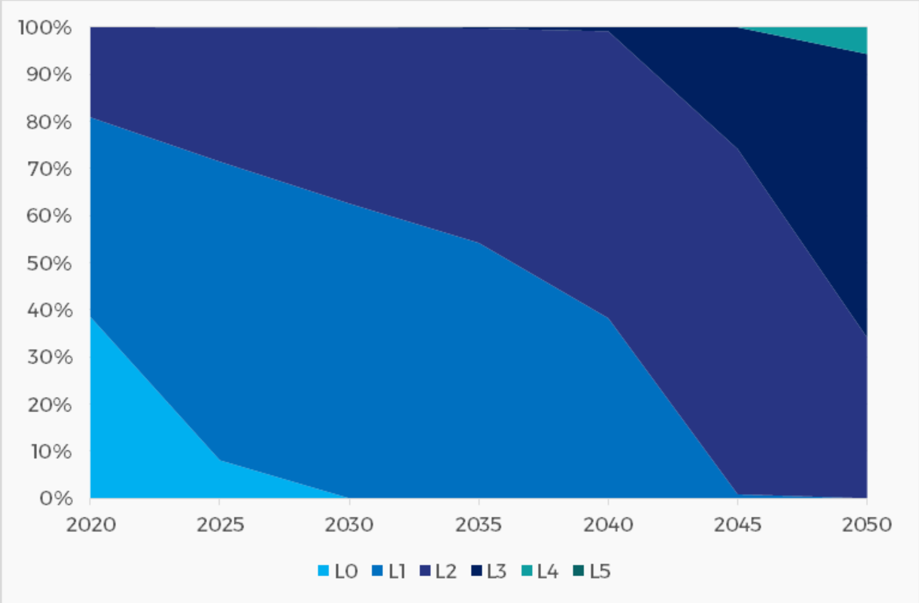


Table B.11 Reference Scenario – Composition of freight vehicles fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	39%	8%	0%	0%	0%	0%	0%
L1	42%	63%	63%	54%	38%	1%	0%
L2	19%	29%	37%	46%	61%	73%	34%
L3	0%	0%	0%	0%	1%	26%	60%
L4	0%	0%	0%	0%	0%	0%	6%
L5	0%	0%	0%	0%	0%	0%	0%

Scenario 1

Figure B.19 Scenario 1 – Composition of freight vehicles fleet by automation level (EU27)

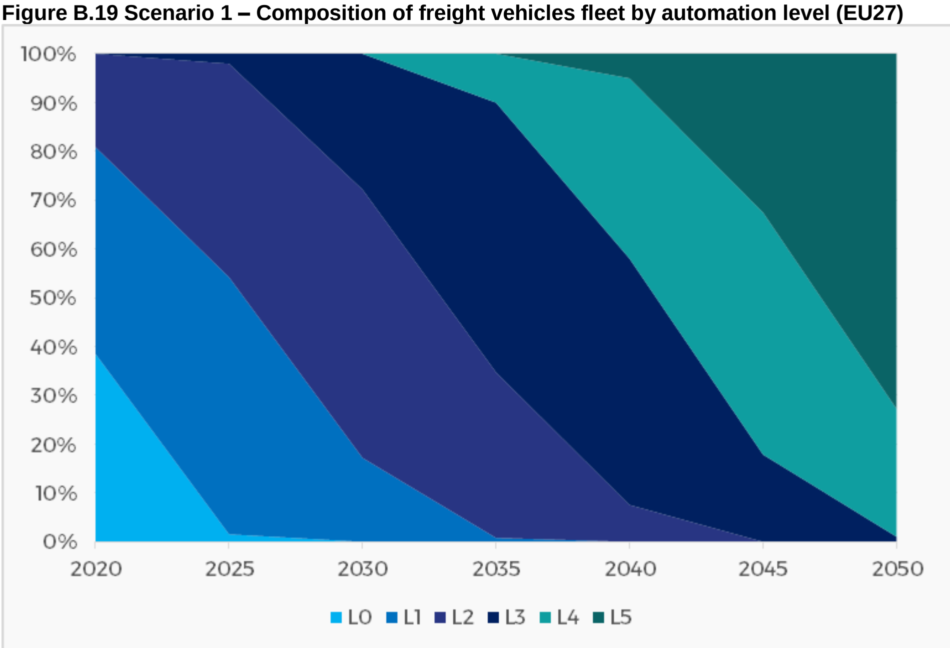


Table B.12 Scenario 1 – Composition of freight vehicles fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	39%	2%	0%	0%	0%	0%	0%
L1	42%	53%	17%	1%	0%	0%	0%
L2	19%	44%	55%	34%	8%	0%	0%
L3	0%	2%	28%	55%	50%	18%	1%
L4	0%	0%	0%	10%	37%	50%	26%
L5	0%	0%	0%	0%	5%	33%	73%

Scenario 2

Figure B.20 Scenario 2 – Composition of freight vehicles fleet by automation level (EU27)

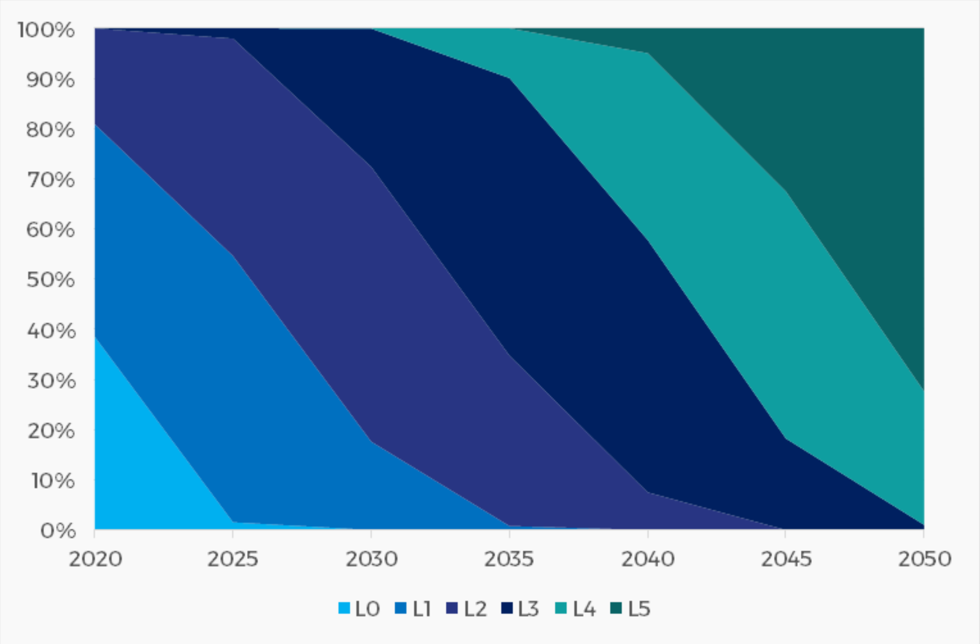


Table B.13 Scenario 2 – Composition of freight vehicles fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	38%	2%	0%	0%	0%	0%	0%
L1	42%	53%	18%	1%	0%	0%	0%
L2	19%	43%	55%	34%	7%	0%	0%
L3	0%	2%	28%	55%	50%	18%	1%
L4	0%	0%	0%	10%	37%	49%	27%
L5	0%	0%	0%	0%	5%	33%	72%

Scenario 3

Figure B.21 Scenario 3 – Composition of freight vehicles fleet by automation level (EU27)

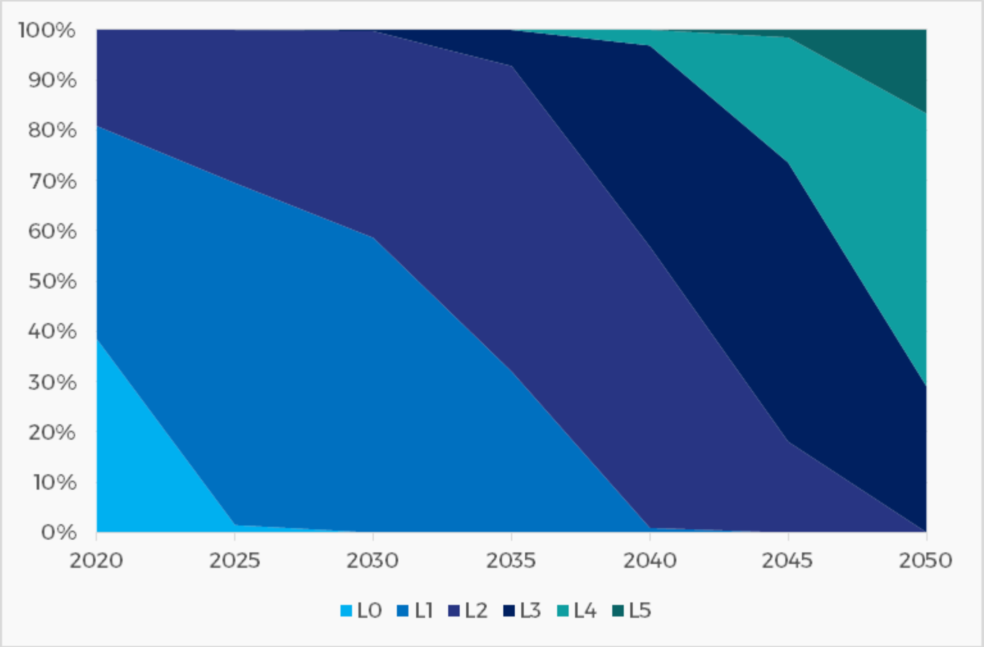


Table B.14 Scenario 3 – Composition of freight vehicles fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	38%	2%	0%	0%	0%	0%	0%
L1	42%	68%	59%	32%	1%	0%	0%
L2	19%	30%	41%	61%	56%	18%	0%
L3	0%	0%	0%	7%	40%	56%	29%
L4	0%	0%	0%	0%	3%	25%	54%
L5	0%	0%	0%	0%	0%	2%	17%

Scenario 4

Figure B.22 Scenario 4 – Composition of freight vehicles fleet by automation level (EU27)

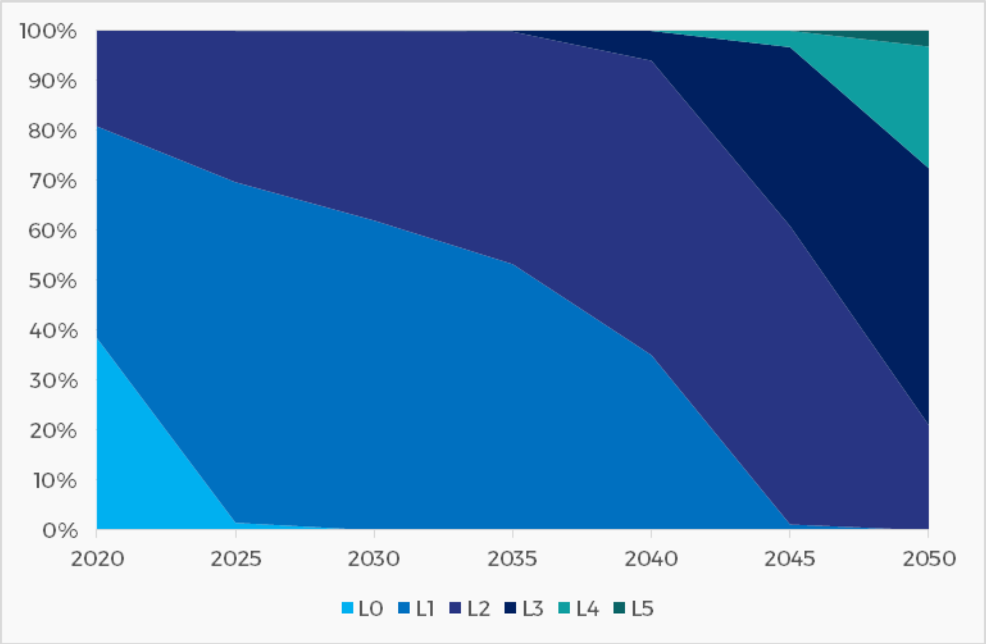


Table B.15 Scenario 4 – Composition of freight vehicles fleet by automation level (EU27)

	2020	2025	2030	2035	2040	2045	2050
L0	38%	2%	0%	0%	0%	0%	0%
L1	42%	68%	62%	53%	35%	1%	0%
L2	19%	30%	38%	47%	59%	60%	21%
L3	0%	0%	0%	0%	6%	36%	51%
L4	0%	0%	0%	0%	0%	3%	24%
L5	0%	0%	0%	0%	0%	0%	3%

Annex C – The Economic and the Synthesis models

Methodology of the models

The ASTRA Model

Overview

ASTRA, which means Assessment of TRAnsport strategies, is an integrated assessment model applied for strategic policy assessment in the transport and energy field since more than 15 years. It covers EU27+3 (Norway, Switzerland and UK) countries and integrates a vehicle fleet model, transport model, emission and accident models, population model, foreign trade and economic model with input-output tables, government, employment and investment models. ASTRA builds on recursive simulations following the system dynamics concept and enables to run scenarios until 2050. The applied Vensim system dynamics software provides sophisticated tools for sensitivity analyses.

Dynamic Macroeconomic Approach

ASTRA aims to capture both the direct and indirect economic impact of a scenario on the entire economy. Macroeconomic analyses require the use of a full mathematical model of an economy including other exchange relationships (e.g. traffic influences). In addition to the calculation of direct net effects, also dynamic, macroeconomic effects are estimated in the macroeconomic analysis. Based on a scenario, an economic impulse is triggered. Direct effects lead to induced effects in year one by cause-effect chains, when the income of an economy is reduced or increased by the impulse. The dynamic analysis then takes into account that the economy has been shifted to a different level and leads to further sectoral value added and employment effects via so-called second-round effects in the following years. In addition to the second-round effects, the analyses of investment and productivity effects (also known as spill-over effects) can lead to further indirect effects on GDP and employment.

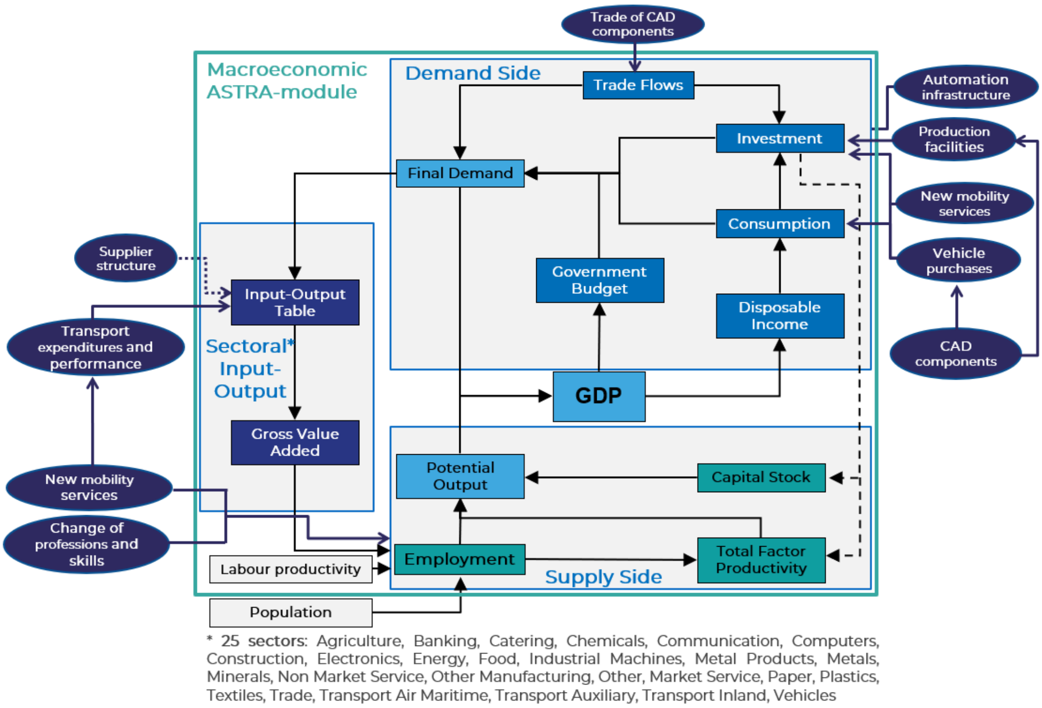
The Economic Module in ASTRA

The Economic module consists of five elements: supply side, demand side, an input-output model based on 25 economic sectors, employment model and government model.

The macro-economic components of ASTRA apply different theoretical concepts e.g. endogenous growth by linking total factor productivity to investments, neo-classical production functions that consider capital, labour and the total factor productivity, Keynesian consumption driven and export driven investment functions.

Figure C.1 shows a conceptual overview of the macroeconomic linkages and selected CAD impulses (blue ellipses) using the ASTRA model.

Figure C.1 The macro-economic module of ASTRA and selected CAD effects



Source: M-Five.

To calculate the gross domestic product (GDP), supply and demand sides are both integrated and balanced. The demand side includes the four main components of final demand. Consumption and investments together with government expenditures and exports form the second quadrant of the Input-Output tables, which is equivalent to final demand, when imports are subtracted. Disposable income of households is calculated based on GDP, the amount of which in turn influences consumption (household demand). The input-output calculation reflects the interactions between the different economic sectors.

This demand side of the economy is complemented by the supply side. Potential output is calculated using the production function via the two production factors capital and labour including the influence of technological progress, which is endogenously modelled as total factor productivity (TFP). The endogenous total factor productivity depends on investments, the network effect of changing transport times in freight transport and changes in sectoral labour productivity.

Via the capital stock and total factor productivity (TFP), an increase in investment leads to increasing production potential and GDP, income and consumption. Investments must be balanced correspondingly. Increased investments in one sector are financed either by under-investments in other sectors, by increasing the costs for the user, by increasing government levies and taxes or by increasing the government deficit. GDP growth enforces a further growth in consumption, triggering investments to meet this new consumption demand. Through input-output changes, investments, consumption and other components of final demand have an impact on value creation. Gross value added, together with sectoral labour productivity, serves as a key driver of employment. These feedback effects between GDP, income, consumption and investment are a key feature of ASTRA and enable the modelling of indirect effects that result from the implementation of policies and instruments.

Gross Domestic Product (GDP)

The main output indicator of the economic module is the **gross domestic product (GDP)** per country. To calculate GDP, supply and demand sides are both integrated and balanced. According to the neo-classical theory of growth, potential output is equal to the real output or (in other words) GDP. The assumption of efficient production processes leads to this equilibrium. The basic model of balanced growth was developed by Solow and Swan (Solow, 1956)[9]. As opposed to the ASTRA model, technical progress is supposed to be an exogenous driver in this theory. Another important theory explaining the growth of GDP is given by the model of Samuelson and Hicks (Allen, 1968)[10]. It is derived from the Keynesian multiplier and accelerator model and tries to simulate business cycles. System Dynamics as underlying methodology allows to combine both theories. This allows overcoming the critical assumptions of the Solow model. GDP is not per se equal to the potential output. In contrast to computable general equilibrium (CGE) models, GDP is driven by the demand and supply side of an economy. The following equation demonstrates the implemented dependency of both sides.

$$GDP_i(t) = \begin{cases} \mathrm{wFDa}_i * FD_i(t) + (1 - \mathrm{wFDa}_i) * PO_i(t) \rightarrow FD_i(t) > PO_i(t) \\ \mathrm{wFDb}_i * FD_i(t) + (1 - \mathrm{wFDb}_i) * PO_i(t) \rightarrow FD_i(t) \leq PO_i(t) \end{cases} \quad (1)$$

with	GDP	=	gross domestic product
	FD	=	final demand
	PO	=	potential output
	wFDa	=	weight of final demand if FD>PO
	wFDb	=	weight of final demand if FD<=PO
	i	=	index for EU27+2 countries
	t	=	Time (Year of calculation)

Final Demand

Final demand is the aggregation of the major demand side indicators: consumption of private households, investments, government consumption and export-import balance. The basic approach is to calculate those variables on the sectoral level and then aggregate them, where necessary, to country level.

$$FD_{i,s}(t) = C_{i,s}(t) + I_{i,s}(t) + GC_{i,s}(t) + (EX_{i,s}(t) - IM_{i,s}(t)) \quad (2)$$

mit	FD	=	final demand
	C	=	private consumption of households
	I	=	investments
	GC	=	government consumption
	EX	=	exports
	IM	=	imports
	s	=	index for the 25 economic sectors
	I	=	index for EU27+3 countries

The **consumption model** in ASTRA aims at simulating the consumption expenditure of private households for goods and services in each of the 25 economic sectors. The first step in the calculation of consumption consists in the differentiation of total disposable income into total income available for each income group. Total disposable income of private households per income group

[9] Solow R M. (1956): A Contribution to the Theory of Economic Growth. In: Quarterly Journal of Economics, vol. 70, pp 65-94.

[10] Allen, R. G. D. (1968): Macro-Economic Theory. A Mathematical Treatment. Macmillan, London.

is used to calculate the potential national consumption of households considering private savings and non-national consumption expenditures.

The ASTRA consumption model is differentiated into two main parts: non-traffic-related consumption and consumption for transport purposes. This approach takes into account substitution effects between non-traffic-related and traffic-related consumption. A decline in consumption in the transport sector leads to a considerable increase in consumption in non-transport sectors and vice versa. Due to the complementarity between transport and other activities and due to incentive effects, there is no full reallocation.

Non-traffic related consumption includes all domestic private consumption, excluding all consumption expenditure for private transport. Input variables in the private consumption of traffic-related goods and services are determined in the Scenario Model as well as in the component model. Net consumer spending on transportation includes car purchases, i.e. private consumption of conventional and innovative car components (see Annex section on Component Model) as well as fuel consumption, expenses for transport services, insurance and the maintenance of cars (see Table 2.2).

The **investment model** constitutes one of the most important models for long-term development of ASTRA. Investments are influenced either by decisions in the transport system or by macroeconomic influences. The investment model calculates investments by private and governmental actors. The procedure for estimating the annual amount of investments differs for traffic-related and non-traffic-related investments.

Various transport-related investments are taken into account in the ASTRA model:
- Investments in transport vehicles (business cars, buses, trucks, trains, planes, ships);
- Investments in transport facilities such as stations or container terminals;
- Transport network investments as part of government investments;
- CAD-infrastructure investments to digitize traffic (see Annex section on infrastructure investment calculations);
- Investments in R&D and the production of components for CAD, e.g. semiconductors (see Annex below).

For non-traffic-related investments, the development is derived from private consumption and exports in the respective sector, from government debt through the influence on interest rate developments and from the utilization of the production inputs.

Government consumption is calculated within the government model and develops roughly according to GDP and employment development in the government sector. For details on the government sub-module see Fermi et al. (2014).

Exports and imports are calculated in the Foreign Trade (FOT) module (see Annex section on the trade module in ASTRA).

Potential Output

Potential output is calculated using the production function of Cobb-Douglas type that incorporates the three major production factors labour supply, capital stock and natural resources as well as technical progress referred to as total factor productivity (TFP). Labour supply, capital stock and total factor productivity are calculated endogenously. The influence of natural resources is yet considered exogenously. The resulting extended Cobb-Douglas function is presented in the following equation:

$$PO_i(t) = bPO_i + cPO_i * TFP_i(t-dt) * L_i(t-dt)^{\alpha} * CS_i(t-dt)^{\beta} * NR_i(t-dt)^{\gamma} \tag{3}$$

with	PO	=	potential output
	bPO	=	calibrated parameter for base level variable
	cPO	=	calibrated parameter for trend factor
	TFP	=	total factor productivity
	L	=	labour supply in working hours
	CS	=	capital stock
	NR	=	natural resources (exogenous)
	α	=	calibrated production elasticity labour supply
	β	=	calibrated production elasticity capital
	γ	=	calibrated production elasticity natural resources
	i	=	index for EU27+3 countries

In contrast to standard Cobb-Douglas functions the elasticities of capital and labour need not add to 1 since calibration is not performed by regressions, but with the Vensim® optimizer, which does not has any restrictions on the functional forms of equations, besides that one should limit the number of parameters calibrated by one optimization to avoid excessive running times.

Capital stock depends on initial gross capital stock, investment (capital goods including transport investments) and scrappage of the capital stock.

Total factor productivity in ASTRA-EC is mostly indigenized considering sectoral labour productivity changes weighted by endogenous sectoral gross-value-added (GVA), endogenous sectoral investments that are weighted by their sectoral innovation potential and changes in freight transport times differentiated for the different goods categories.

The development of human resources in terms of **labour supply** depends on the dynamics within the EU27+3 labour markets. Labour supply is expressed in Million hours worked per year by all employed and self-employed persons in an economy. The number of full-time-equivalent employment is the baseline for its calculation. Especially in times of crisis, labour supply contains more information about the labour market then just employment. Reduced working hours as a strategy in times of de-creasing demand for products and services can be reflected via this production factor.

(Sectoral) Employment

The **employment model** simulates the development of national labour markets, estimates sectoral employment trends, distinguishes between full-time and part-time employment and computes unemployment. It provides valuable information for several other modules and variables such as the production function.

The most important input to the employment model is gross-value added provided by the sectoral interchange model (input-output table). Relating this to exogenous labour productivity, i.e. reversing the usual calculation of productivity as the ratio between value-added and employment, the number of full-time-equivalent (FTE) employed is calculated:

$$FTE_{i,s}(t) = \frac{GVA_{i,s}(t) * 1000000}{LP_{i,s}(t)} \tag{4}$$

with	FTE	=	full-time-equivalent employment [Persons]
	GVA	=	gross-value added [Mio EURO2005]
	LP	=	labour productivity [EURO2005/FTE]
	s	=	index for 25 economic sectors
	i	=	index for EU27+3 countries

Labour productivity per sector is derived from statistical numbers for full-time-equivalent employment and gross value-added per sector. For future development, an exogenous trend for labour productivity is assumed. This trend is derived from EC DG ECFIN (2012)[11]. The model considers also an endogenous driver depending on the level of unemployment. If the level of unemployment achieves a rate below 5 %, then the ASTRA-EC model assumes a stronger future increase of labour productivity in order to compensate the probable lack of employees. This reaction could be observed in the past and will be of strong importance when the number of labour forces in many EU member states will decline due to ageing societies.

The integration and continuation of statistical trends for part-time and full-time employed per sector allow the estimation of total full-time and part-time employment per sector.

This requires a split of FTE-employment into a share of persons working full-time i.e. having a 5-days job with average weekly working hours between 35 and 45 hours depending on the country of residence and a share of persons working part-time. Base data for developing the part-time employment model is taken from the Eurostat database. That enables to calculate the share of part-time employed on the FTE-employment and to derive a multiplier on how many part-time employed constitute one FTE-employed. Based on these two inputs total sectoral employment can be calculated in ASTRA-EC by the following equation:

$$\begin{aligned} EMP_{i,s}(t) = FTE_{i,s}(t) * \left(1 - \left(sPT_{i,s} * trPT_{i,s}(t)\right)\right) \\ + FTE_{i,s}(t) * (sPT_{i,s} * trPT_{i,s}(t)) * PTF_{i,s} \end{aligned} \tag{5}$$

with	EMP	=	total employment [persons]
	FTE	=	full-time-equivalent employment [Persons]
	sPT	=	sectoral share part-time employment
	trPT	=	trend part-time employment
	PTF	=	part-time factor reflecting the number of part-time employed equivalent to on full-time employed
	s	=	index for 25 economic sectors
	i	=	index for EU27+3 countries

11 European Commission. Directorate-General for Economic and Financial Affairs (2012): The 2012 Ageing Report: Economic and budgetary projections-for the EU27 Member States (2010-2060), European Economy 2/2012.

A growth trend for the share of part-time employed is considered. This growth trend is one of the exogenous leverages to adapt the economic growth as well as the labour market for the future simulation period up to 2050.

Finally, the employment model derives unemployment based on total employment and active labour force that is computed in the Population model based on the number of labour forces per country and the country-specific activity rate extracted from Eurostat. Due to the demographic decline in EU27+3 until 2050 the activity rate, representing the share of labour force people that are active on the labour market, is assumed to increase slightly in order to avoid severe labour shortages.

The Trade Module in ASTRA

Foreign trade will heavily influence future economic growth. In the ASTRA model, trade flows are endogenously modelled. The Trade module (FOT) can be differentiated into two parts: The first part represents foreign trade between the EU27+3 countries (Norway, Switzerland, UK), the so-called INTRA-EU trade model. The second part simulates foreign trade between the EU27+3 countries and countries in the rest-of-the world, the EU-RoW trade model. Countries in the rest-of-the-world are assigned to 15 regions, namely Arabian-African Oil Exporters, Asian Oil Exporters, Oceania, Brazil, China, East Asia, India, Japan, Latin America, North America, Res-of-the-World countries, Russian Federation, South Africa, South Asia, and Turkey.

The two models are differentiated into bilateral trade flows by country pair for a set of economic sectors. As the manufacturing sectors dominate exports, the originally 25 economic sectors are aggregated to 17 sectors in both trade models, which are 15 manufacturing sectors, one transport services sector and one sector standing for all trade flows in other service sectors.

Three endogenous and one exogenous factor determine the development of trade between EU27+3 countries:

- different level of sectoral labour productivity of the two trading partners;
- growth of GDP of the importing country;
- world GDP growth;
- generalised time of passenger transport between the two trading partners; and
- generalised costs of freight transport between the two trading partners.

In this project, exports stemming from the production and export of automated vehicles as well as single CAD-components are specifically modelled in the component model and linked to the respective sectors in the trade model.

The resulting sectoral export-import flows are fed back into the Economic module as part of final demand and national final use, respectively. Exports are one of the major drivers of investment.

For further information on detailed modelling of the Trade model, see Fermi et al., 2014.

Economic Sectors in ASTRA with reference to NACE

The following table provides a comparison between the sectors in ASTRA, NEMESIS and the respective NACE-sectors including a categorisation in terms of CAD relevance.

Table C.1 Relations between NACE, NEMESIS and ASTRA sectors as well as relevance for CAD

NACE SECTOR		NEMESIS (30 Sectors)	ASTRA (25 Sectors)	CAD relevance
A	Agriculture, Forestry and Fishing	Agriculture	Agriculture	low
B	Mining and quarrying	Coal and Coke	Metals	low
		Oil & Gas Extraction	Minerals	low
			Energy	medium
C10-C12	Manufacture of food products; beverages and tobacco products	Food. Drink & Tobacco	Food Other Manufacturing	low low
C13-C15	Manufacture of textiles, wearing apparel, leather and related products	Tex. Cloth & Footwear	Textiles	low
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Other Manufactures	Other Manufacturing	low
C17	Manufacture of paper and paper products	Paper & Printing Products	Paper	low
C18	Printing and reproduction of recorded media	Paper & Printing Products	Paper Other Manufacturing	low low
C19	Manufacture of coke and refined petroleum products	Refined Oil	Energy	medium
C20	Manufacture of chemicals and chemical products	Chemicals	Chemicals	low
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	Chemicals	Chemicals	low
C22	Manufacture of rubber and plastic products	Rubber & Plastic	Plastics	low
C23	Manufacture of other non-metallic mineral products	Non Metallic Min Products	Minerals	low
C24	Manufacture of basic metals	Ferr & non Ferrous Metals	Metals	low
C25	Manufacture of fabricated metal products, except machinery and equipment	Metal Products	Metal Products	low
C26	Manufacture of computer, electronic and optical products	Office machines	Computers	high
C27	Manufacture of electrical equipment	Electrical Goods	Electronics	high
C28	Manufacture of machinery and equipment n.e.c.	Agr & Indus. Machines	Industrial Machines	medium
C29	Manufacture of motor vehicles, trailers and semi-trailers	transport Equipment	Vehicles	high

NACE SECTOR		NEMESIS (30 Sectors)	ASTRA (25 Sectors)	CAD relevance
C30	Manufacture of other transport equipment	transport Equipment	Vehicles	high
C31-C32	Manufacture of furniture; other manufacturing	Other Manufactures	Other Manufacturing	low
C33	Repair and installation of machinery and equipment	Other Manufactures	Trade	medium
D	Electricity, gas, steam and air conditioning supply	Gas Distribution	Energy	medium
		Electricity		medium
E36	Water collection, treatment and supply	Water Supply	Energy	low
E37-E39	Sewerage, waste management, remediation activities	Other Manufactures	Non Market Services	low
F	Construction	Construction	Construction	high
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles	Distribution	Trade	high
G46	Wholesale trade, except of motor vehicles and motorcycles	Distribution	Trade	high
G47	Retail trade, except of motor vehicles and motorcycles	Distribution	Trade	high
H49	Land transport and transport via pipelines	Inland Transports	Transport Inland	high
H50	Water transport	Sea & Air Transport	Transport Air Maritime	low
H51	Air transport	Sea & Air Transport	Transport Air Maritime	low
H52	Warehousing and support activities for transportation	Other Transports	Transport Auxiliary	medium
H53	Postal and courier activities	Other Transports	Communication	high
I	Accommodation and food service activities	Lodging & Catering	Catering	low
J58	Publishing activities	Communication	Other Market Services	low
J59-J60	Motion picture, video, television programme production; programming and broadcasting activities	Communication	Other Market Services	low
J61	Telecommunications	Communication	Other Market Services	medium
J62 J63	Computer programming, consultancy, and information service activities	Communication	Other Market Services	medium
K64	Financial service activities, except insurance and pension funding	Bank. Finance & Insurance	Banking	low
K65	Insurance, reinsurance and pension funding, except compulsory social security	Bank. Finance & Insurance	Banking	medium
K66	Activities auxiliary to financial services and insurance activities	Bank. Finance & Insurance	Banking	low
L	Real estate activities	Bank. Finance & Insurance	Other Market Services	low

NACE SECTOR		NEMESIS (30 Sectors)	ASTRA (25 Sectors)	CAD relevance
M69-M70	Legal and accounting activities; activities of head offices; management consultancy activities	Other Market Services	Other Market Services	low
M71	Architectural and engineering activities; technical testing and analysis	Other Market Services	Other Market Services	medium
M72	Scientific research and development	Other Market Services	Other Market Services	medium
M73	Advertising and market research	Other Market Services	Other Market Services	medium
M74-M75	Other professional, scientific and technical activities; veterinary activities	Other Market Services	Other Market Services	medium
N77	Rental and leasing activities	Bank. Finance & Insurance	Other Market Services	medium
N78	Employment activities	Other Market Services	Other Market Services	medium
N79	Travel agency, tour operator reservation service and related activities	Other Market Services	Catering	low
N80-N82	Security and investigation, service and landscape, office administrative and support activities	Other Market Services	Other Market Services	medium
O	Public administration and defence; compulsory social security	Non Market Services	Non Market Services	low
P	Education	Non Market Services	Non Market Services	low
			Other Market Services	low
Q86	Human health activities	Non Market Services	Non Market Services	low
			Other Market Services	low
Q87-Q88	Residential care activities and social work activities without accommodation	Non Market Services	Non Market Services	low
R90-R92	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities	Non Market Services	Non Market Services	low
			Other Market Services	low
R93	Sports activities and amusement and recreation activities	Non Market Services	Other Market Services	low
S94	Activities of membership organisations	Non Market Services	Non Market Services	medium
S95	Repair of computers and personal and household goods	Other Market Services	Other Market Services	low
S96	Other personal service activities	Other Market Services	Other Market Services	low

Source: M-Five, SEURECO.

Mobility Service Model

ASTRA simulates transport services employment based on endogenous transport demand, transport costs and employment parameters. For this project, we have substituted endogenous transport demand and costs with Scenario Model expenditures results for the modes described in this project. We have also differentiated the model structure to account for all these transport services as well as distinguish conventional and automated modes. Finally, we have implemented keys for driver/ non-driver employment and various groups of professions within the non-driver category. The resulting national figures have been further broken down to regional figures (NUTS-2 zones) in the synthesis model (description further below).

Put simply, the model structure for transport services is guided by the idea of how much money is at the disposal of transport services companies and how many people will generally be employed using this money. You may argue that the reasoning should be in the opposite direction, that a certain number of employees are required to operate a transport services and that this determines the cost. However, given the structure of the model and the inputs from the Scenario Model, starting from revenues to get employment is the practical way forward. Employment requirements / skills are reflected in the employment parameters and so are typical structures of expenses and the use of financial resources (such as high expenses for staff compared to vehicle costs, high or low profit margins etc).

In a first step, we derive value added from total revenues. According to input-output tables from Germany, value added is generally around 50% of total revenues, meaning that the other 50% are inputs from other sectors (vehicle manufacturers, petroleum industry etc.). Value added includes profits as well expenditures that are not used to procure inputs, such as salaries and depreciation costs. The share of value added is higher than 50% in some cases (taxi) and lower in others (express services/ light-duty vehicles). However, this differentiation has not been a focus area of our work in this project, as the differentiation of employment dynamics rests predominantly on the employment parameters.

These employment parameters determine how many people are employed per million euros of value added. Parameters range from 5 (car-sharing) to 40 employees per million euros of value added for high income countries. For countries with lower GDP per capita, parameters have been increased somewhat – as the same amount of money available can be used to pay more salaries when these salaries are lower.

Employment parameters for automated modes have been modelled on similar traditional modes (bus – robo-bus, taxi – robo-taxi, taxi – ride-sharing etc) and their respective non-driver employment. What CAD does is basically replace the driver, so we removed driver job creation in the model for automated modes. Residual, non-driver employment has been increased above this level for passenger transport services to account for extra needs for guidance and customer services as passengers are starting to get used to the new transport services. This applies mostly to the pilot phase and gradually phased out in the limited roll-out stage. When the service gets more established, we assume some efficiency gains, reducing employment parameters by 10 to 30%.

Component Model

ASTRA features a vehicle component model, which is used to estimate the value of components installed in vehicles. The component model forms the link between vehicle fleet scenarios and impact to economic sectors. It is adapted to the development of CAD technologies and their expected effects on the economy, especially sectoral jobs in manufacturing that depend on the components built in future cars, buses and trucks. The component model is using a limited number of components, including CAD components, to estimate the costs of a finished vehicle as the sum of the costs of the individual components plus research & development, vehicle assembly and overhead. For a European mid-size car, these costs account for around 70% of the sales price. The other 30% of the sales price are marketing, manufacturer margin, dealer margin, dealer support and logistics (Holweg, 2008)[12].

The Center of Automotive Management (CAM) has researched single CAD components. Since they are based more on software than the typical vehicle segments, we refer to them here as *digital components*. Table C.2 shows some of these components in detail, which are particularly relevant for performing CAD-related services.

Table C.2 Digital components, which are relevant for CAD-based services

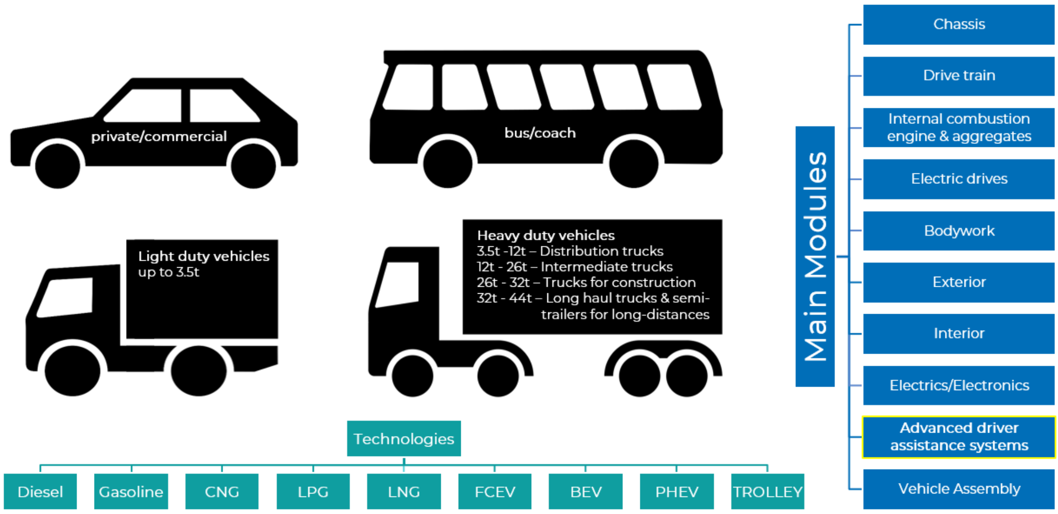
Component	Description
Connectivity Box	Hardware component for networking the vehicle with the cloud, including (embedded) SIM card
GPS	Global Positioning System, global navigation satellite system for positioning
ADAS	Advanced Driver Assistant System, extended driver assistance systems for longitudinal/transverse control through to autonomous driving
Radar	Radio detection and ranging, detection and positioning methods and devices based on electromagnetic waves in the radio frequency range (radio waves), in particular used in driver assistance systems for longitudinal guidance and blind spot detection
Lidar	Light detection and ranging, a method similar to radar for optical distance and speed measurement, especially in the medium and long range, important sensor technology for autonomous driving functions
Ultrasound	Distance sensors based on ultrasound, especially at close range (e.g. when parking)
Sensoric	Sum of sensor components, e.g. for autonomous driving functions (ultrasound, radar, lidar, etc.)
Actuatoric	Actuators convert signals (e.g. commands issued by the control unit) into mechanical movement or other physical variables (e.g. pressure or temperature) and thus actively intervene in a control process, e.g. steering process during autonomous driving
Virtual Key	software-based access authorization system, e.g. via app
SW Com Modul	Software-based communication of the charging infrastructure with the vehicle, e.g. identification and payment
AI	artificial intelligence

Source: Center of Automotive Management (CAM).

Initial component costs refer to the year 2020. The development of costs is modelled in ASTRA directly. The following figure illustrates the vehicle fleet cohorts, single components and drivetrain technologies that the component models covers.

[12] Holweg, M. (2008). The evolution of competition in the automotive industry. In Build to order (pp. 13-34). Springer, London.

Figure C.2 Segments, main modules and technologies of the vehicle component model



Source: M-Five.

The component model distinguishes between the following ten components:

- Chassis;
- Drive train;
- Internal combustion engine & aggregates (only for diesel, gasoline, CNG, LPG and PHEV);
- Electric drives (only for FCEV, BEV and PHEV);
- Bodywork;
- Exterior;
- Interior;
- Electrics/electronics without ADAS;
- Advanced Driver Assistance Systems (ADAS);
- Vehicle assembly or conception of the complete vehicle.

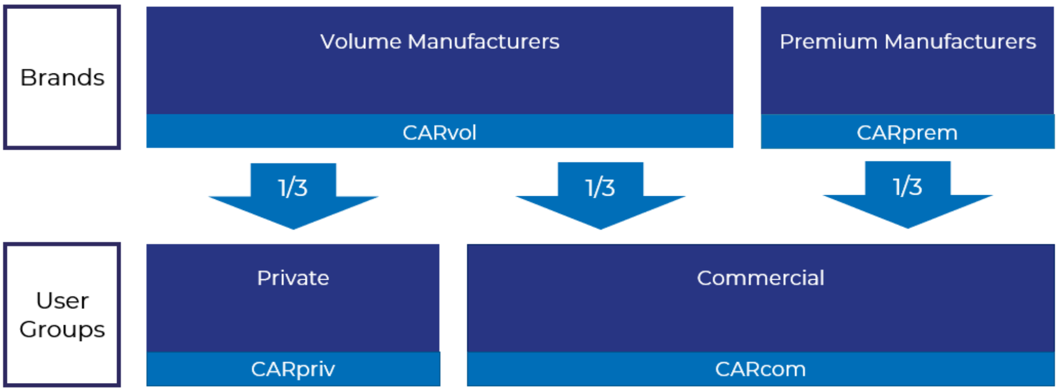
The model includes cars, light and heavy-duty vehicles as well as buses/ coaches. For passenger cars, it differentiates between private and commercial user groups. For buses, we distinguish public service buses and coaches. Commercial vehicles include light commercial vehicles (up to 3.5t), distribution trucks (3.5t -12t), intermediate trucks (12t - 26t), trucks for construction (26t - 32t), and long haul trucks and semitrailers for long-distances (32t - 44t).

The component model also includes the differentiation between technologies of drive types. For passenger cars and light commercial vehicles these are Diesel, Gasoline, Compressed natural gas (CNG), Liquefied petroleum gas (LPG) (only for cars), Fuel cell (FCEV), Battery electric (BEV), and Plug-in hybrid (PHEV). Coaches or heavy trucks can also be powered by liquefied natural gas (LNG). Public service buses and heavy trucks can also be powered by electricity from an overhead line.

Component costs for cars

Cars are purchased by two groups of vehicle owners: private and commercial car owners. By assumption, one third of new car registrations are by private vehicle owners who buy vehicles from volume manufacturers. Two thirds are commercial vehicle owners, who purchase cars half from volume manufacturers and half from premium manufacturers.

Figure C.3 Car types and user groups in the vehicle component model



Source: M-Five.

Most newly registered cars have conventional drivetrain technologies with gasoline or diesel engines. Other cars are available with different drivetrain technologies. According to research, the gasoline engine is in any case the technology with the lowest acquisition costs. Thereby, the basic cost structure is based on vehicles with a gasoline engine. Initially, estimations neglect the component costs for driver assistance systems and include only actual manufacturing costs.

To estimate manufacturing costs for gasoline cars, taxes and margins are deducted from list prices as well as ADAS component costs depending on the SAE level. The residual value is distributed among components according to the distribution key shown in Figure C.4.

In order to determine the component costs for a "basic vehicle", the production costs without VAT on the basis of average acquisition costs A of the gasoline cars are:

$$A * (1 / (1 + VAT)) * (1 / 1.31)$$

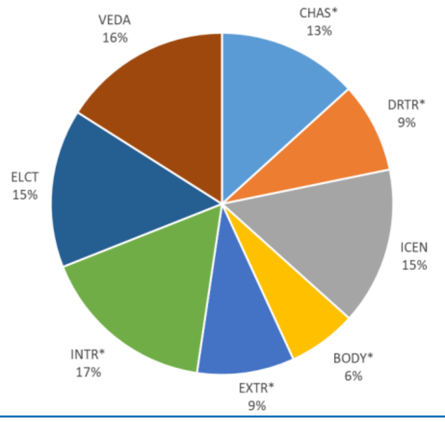
based on Holweg (2008)[13]. The component costs of driver assistance systems and their development depend on the scenarios considered. Therefore, they are initially subtracted from manufacturing costs, just as costs for vehicle development and assembly. Costs for vehicle development and assembly costs are estimated at 16% of manufacturing costs (Oliver Wyman, 2018)[14]. Based on ika (2014)[15], remaining costs cover the “physical” components of a gasoline car with the following shares: chassis 13%, drive train 9%, internal combustion engine & aggregates 15%, bodywork 6%, exterior 9%, interior 17%, electrics/electronics 15%, vehicle development and assembly 16%.

[13] Holweg, M. (2008). The evolution of competition in the automotive industry. In Build to order (pp. 13-34). Springer, London.
[14] Oliver Wyman (2018). FAST 2030 – Future Automotive Industry Structure until 2030.
[15] ika (2014): Modellierung der zukünftigen elektromobilen Wertschöpfungskette und Ableitung von Handlungsempfehlungen zur Stärkung des Elektromobilitätsstandortes NRW (EM1006 – eVchain.NRW). Gemeinschaftlicher Abschlussbericht.

Figure C.4 Cost structure of gasoline passenger cars by main modules

Component	Abbreviation
Chassis	CHAS*
Drive train	DRTR*
Internal combustion engine & aggregates	ICEN
Bodywork	BODY*
Exterior	EXTR*
Interior	INTR*
Electrics/Electronics	ELCT
Vehicle development and assembly	VEDA
* basic vehicle (HDV/BUS only)	

Share of component costs (gasoline car)



Source: M-Five based on ika (2014) and Oliver Wyman (2018).

By assumption, the total component costs, derived from the shares shown above, are representative for all vehicles of volume and premium manufacturers. Incremental component costs of other internal combustion engines (diesel, LPG, CNG, PHEV) and electrified drivetrains (BEV, PHEV, FCEV) result from the differences in manufacturing costs of vehicles with comparable features. Total costs for alternative drivetrains are hence the drivetrain costs for gasoline cars plus incremental costs. For PHEV, 50% of the costs are attributed to the internal combustion engine and 50% to the electric drivetrain.

The evaluation considers the following car models in combination with numbers of new registrations in Germany (Jan-Feb 2020), where 22% of cars in the EU and EFTA area were registered. This approach allows to derive representative costs for cars from volume manufacturers (light blue) and premium manufacturers (white):

Table C.3 Car models considered in the passenger cars component model

Brand	Model series	New registrations*** Germany Jan.- Feb. 2020	diesel	gasoline	cng	lpg	fcev	bev	phev
VW	GOLF	24,610	x	x				x	
VW	TIGUAN	12,113	x	x					
VW	PASSAT	11,811	x	x					x
FORD	FOCUS	10,916	x	x					
VW	POLO	8,790	x	x	x				
BMW	3ER	8,708	x	x					x
OPEL	CORSA	7,456	x	x				x	
MERCEDES	GLK, GLC	7,011	x	x					x
RENAULT	CLIO*	5,434	x	x					
FIAT	500	4,746		x		x		x	
AUDI	Q5**	3,787	x	x					
VW	UP	3,714		x	x			x	
RENAULT	ZOE*	3,150						x	
AUDI	E-TRON**	1,163						x	
HYUNDAI	IONIQ	924		x				x	x

* Direct comparison Renault Clio with Renault Zoe.
** Direct comparison Audi Q5 with Audi e-tron.
*** Source: KBA (2020)[16].

Previous publications on component costs do not differentiate according to the level of equipment in driver assistance systems. Since the development of employment and value added through connected and automated driving is the focus of this study, this aspect requires particular consideration. By assumption, cars from volume manufacturers that are newly registered today already have technologies that allow SAE level 1 of automated driving, i.e. in certain situations, the vehicle can either perform longitudinal guidance (regulate speed) or lateral guidance (steering) independently. Newly registered cars from premium manufacturers have technologies that meet SAE level 2. In certain situations, the vehicle can independently perform driving manoeuvres with longitudinal and lateral guidance. This is the case, for example, if lane departure warning system and adaptive cruise control are active at the same time or if the vehicle is parking independently in a parking space. Costs for components that allow a certain level of automated driving have been provided by VTT. The component costs of driver assistance systems of the same SAE level do not differ between the vehicle cohorts (cars, buses, light and heavy commercial vehicles), however the year of market launch may differ depending on the scenarios considered.

Component costs for light commercial vehicles up to 3.5 tons (GVW)

Component costs for light commercial vehicles up to 3.5 t (GVW) are determined analogously to the component costs for passenger cars with the only difference that the estimation is not based on gasoline vehicles but on diesel-powered vehicles as cheapest and most demanded drivetrain.

It is assumed that gasoline vehicles with comparable engine performance can be obtained at no additional costs. By assumption, most newly registered light commercial vehicles already have driver assistance systems, i.e. SAE level 2. A selection of the EU's best-selling models of 2018

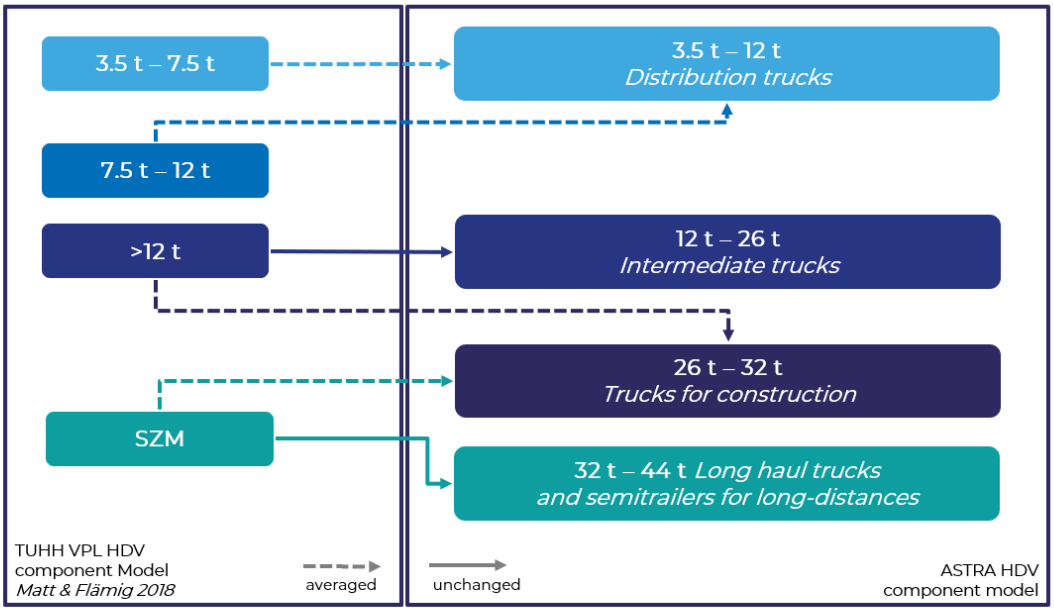
16 KBA 2020: FZ10.1 Neuzulassungen von Personenkraftwagen nach Marken und Modellreihen im Februar 2020.

according to ICCT (2020)[17] was taken into account: Ford Transit, Mercedes Sprinter, VW Transporter, Fiat Ducato, Renault Kangoo, Citroën Berlingo and Renault Master.

Component costs for heavy commercial vehicles

Component costs for heavy commercial vehicles are taken from a study of the German Mobility and Fuel Strategy commissioned by the German Federal Ministry of Transport and Digital Infrastructure (Matt & Flämig, 2018)[18]. Unlike the component costs for cars and light commercial vehicles that are based on the sales price, component costs for heavy commercial vehicles are determined bottom-up. Size classes of vehicles were adapted to the weight classes in ASTRA according to the following figure.

Figure C.5 HDV component model in ASTRA



Source: M-Five based on Matt & Flämig (2018).

Following Matt & Flämig (2018) the components body, drive train, chassis, exterior and interior are combined into a “basic” vehicle. The component costs for vehicle electronics correspond to "other costs" in the model by Matt & Flämig (2018) and are EUR 2,777. Essential components of safety electronics are already included in the costs for driver assistance systems. By assumption, new heavy-duty vehicles of all sizes will have technologies that meet SAE level 3 in 2020. The costs for vehicle development and assembly correspond to 33% of the manufacturing costs. Matt & Flämig (2018) apply a factor of 1.53 (+53%) for margin / assembly etc. In the ASTRA component model, manufacturing costs are without the manufacturers and dealer margins, so that only the costs for vehicle development and assembly are to be taken into account. By assumption, battery cells cost 85 EUR/kWh in 2020 (Horváth & Partners, 2019)[19].

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17 ICCT (2020): EUROPEAN VEHICLE MARKET STATISTICS. Pocketbook 2019/20. Available on https://theicct.org/sites/default/files/publications/European_vehicle_market_statistics_20192020_20191216.pdf.

18 Matt and H. Flämig (2018): Komponentenmodell und TCO-Rechnung Lkw. As part of the project "Financial incentives for the decarbonisation of transport" of the German Mobility and Fuel Strategy commissioned by the German Federal Ministry of Transport and Digital Infrastructure.

19 Horváth & Partners (2019). Worldwide price development for lithium-ion batteries. Available on https://de.statista.com/statistik/daten/studie/534429/umfrage/weltweite-preise-fuer-lithium-ionen-akkus/.

Component costs for buses and coaches

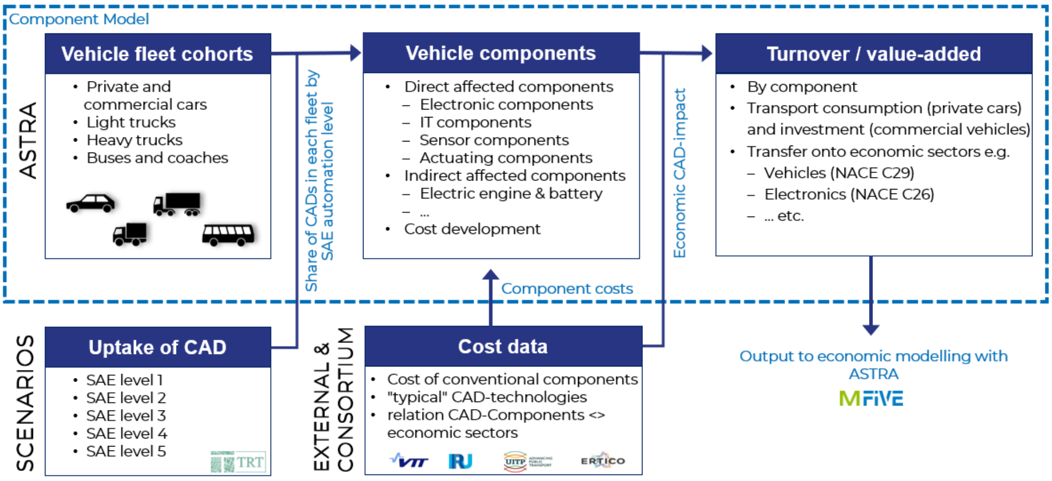
The component costs of the drivetrain technologies (internal combustion engine or electric drivetrain) for buses and coaches are derived from typical engine performances of heavy-duty vehicles. The engine power of regular buses corresponds approximately to the HDV-GVW2 class (intermediate trucks). The HDV-GVW4 class (long haul trucks and semitrailers for long distances) is used for coaches. Consumer electronics such as screens, loudspeakers, WIFI etc. are part of the component electronics/electrics. Total costs of regular diesel buses (approximately EUR 300,000) and battery-electric regular buses cost (approximately EUR 600,000) agree with several independent sources[20].

Component modelling and link to economic variables

The component model forms the link between vehicle fleet scenarios and impact to economic sectors based on the cost estimates of components installed in vehicles. It is adapted to the development of CAD technologies and their expected effects on the economy.

Figure C.6 gives an insight of the vehicle component model, its data sources and links. It has two input resources: on the one hand, the scenario input of the uptake of CAD-Technologies by different automation levels and the shares in the fleet; on the other hand, the costs of individual components as explained above and their relation to economic sectors. The classification of the fleets builds on the vehicle fleet cohorts as an ASTRA input. Together we get costs of single components by fleet, automated driving level and technology. Each component has a technology-specific price development up to 2050 adapted to the development of the Scenario Model. Finally, the component model is transformed into economic data in orientation to the levels of the economic sectors of the EU (NACE categories).

Figure C.6 Modelling approach of the vehicle component model



Source: M-Five.

Vehicle prices will change over the period up to 2050 due to several developments. Due to increasing economies of scale, it can be assumed that component costs will generally decrease, especially for vehicles with new technologies. Due to increased demands on efficiency and emission control, cost reduction potential of vehicles with combustion engines is limited. Compared to today's cost assumptions, the costs of advanced driver assistance systems for higher SAE levels will decrease considerably in order to facilitate a CAD uptake as assumed in the Scenario Model. Autonomous vehicles can only become an important part of everyday mobility if, from the

[20] https://ecomento.de/2019/02/18/verband-bemaengelt-lieferbarkeit-und-preise-von-elektrobussen/; https://www.br.de/nachrichten/wirtschaft/zu-wenig-foerdermittel-fuer-die-energiewende-im-nahverkehr,RXzF8ii; https://correctiv.org; https://www.golem.de/news/bvg-berlins-neue-e-busse-sind-teuer-1906-142155.html.

customer's point of view, vehicle use is safe, attractive and competitively priced. Each component has a distinct price development up to 2050 based on a technology-specific learning rate and sales volumes that are stemming from the Scenario Model.

The vehicle prices are composed of the costs of the 10 differentiated components. Margins of original equipment manufacturers (OEMs) account on average for 7.2% with regard to production costs (Roland Berger/ Lazard, 2019)[21]. In addition, country-specific markups for sales, marketing etc. are added that account for approximately 50% in accordance with literature. The vehicle prices therefore take consider the different price levels in the respective countries.

Considering new registrations of vehicles from the Scenario Model and subtracting the share of imported vehicles by country, based on OICA (2019)[22], allows to calculate the domestic turnover of vehicles. In terms of value, the purchase of vehicles is passed on as a demand vector to the economic sectors in the economic module of ASTRA. Privately procured cars are included in the economic models as (transport) consumption, whereas commercially procured cars, trucks and buses are included as (transport) investment.

Table C.4 shows the mapping of vehicle components to the corresponding economic sectors. Conventional vehicle components such as chassis, drive train, internal combustion engine, body work, exterior, interior, and vehicle assembly (as the core business of OEM) are fully assigned to the sector Vehicles. Electric drives are allocated to the sectors Vehicles, Metals, Chemicals and Electronics. Cell manufacturing mostly belongs to chemicals, power electronics to electronics, whereas the manufacturing of battery packages remain in the vehicles sector. The component electronics is divided evenly to the sectors vehicles and electronics. Advanced driver assistance systems belong to the sectors Electronics, Computer, Communication and Other Market Services. Computing power increases continuously along SAE level with a jump from level 3 to level 4, whereby the share of the sector Computer is increasing with increasing SAE level. The sector Communication provides telecommunications, GPS and sensors. The sector Other Market Services ensures the provision of relevant software.

Table C.4 Mapping of vehicle components to economic sectors in ASTRA

Component	ASTRA-Sector
Chassis	Vehicles
Drive Train	Vehicles
Internal Combustion Engine	Vehicles
Electric Drives	Vehicles, Metals, Chemicals, Electronics (depending on vehicle)
Body Work	Vehicles
Exterior	Vehicles
Interior	Vehicles
Electronics	Vehicles, Electronics
Advanced Driver Assistance Systems	Computer, Electronics, Communication, Other Market Services (depending on SAE level)
Vehicle Assembly	Vehicles

Source: M-Five.

21 Roland Berger/ Lazard (2019): Global Automotive Supplier Study 2019. Available on https://www.lazard.com/media/451032/global-automotive-supplier-study-2019.pdf.

22 OICA (2019): Sales and Production Statistics. Available on http://www.oica.net/category/production-statistics/2019-statistics/ and http://www.oica.net/category/sales-statistics/.

In addition to the domestic market, the component model calculates the export of entire automated vehicles as well as the export of individual components.

Following the same approach as explained above for domestic sales, turnover of exports is modelled considering new registrations of vehicles and the share of exported vehicles by country based on OICA (2019).

The calculation of turnover stemming from the export of single components is based on inputs by the Centre of Automotive Management (CAM) on company data of the vehicle and supplier industry including the identification of CAD-related cluster regions and the derivation of market shares. Exporters are clustered in countries with automotive suppliers as well as technology and software companies. Exporters of a full range of components have been identified in France (Valeo), Germany (Bosch, Continental, ZF, Schaeffler), Ireland (Aptiv), and Sweden (Autoliv). CAD components, such as sensors, lidar, software etc., are inter alia produced in Germany (Hella, Tyssen-Krupp, ARGO AI, Audi), Italy (PRIVAT), The Netherlands (NXP semiconductors), Sweden (Volvo/Autoliv/Ericsson), and Hungary (Bosch, Draper, Nvidia, Tamares). Europe is particularly strong in the field of CAD innovations with a share of CAD innovations from European suppliers of 68 to 70% according to CAM. From this, a significantly higher CAD export share of the European suppliers compared to the imports of the non-European suppliers (about 9%) can be derived. CAM estimates the export share of European suppliers at around 15 percent. By assumption, the future development of component exports develops corresponding to exports of entire vehicles.

In a final step, the vehicle and component exports per country are assigned to the respective sectors (see Table C.4) in the ASTRA export module, which in turn is transferred to final demand.

Investments in R&D and production facilities of CAD-components

To take into account the importance of investments for the macroeconomic impact of CAD, investments in production facilities for new CAD-relevant vehicle components have been estimated at national level. Relevant future technology for automated vehicles on the hardware side will be the production of semiconductors (chips) for high and robust computing power as well as semiconductors required to build sensors. In addition, software will also play an important role for CAD. It is also crucial for the development of CAD-components to invest in R&D of new generations in order to secure or expand production, i.e. value creation, in Europe.

As there is not a uniform source on such investments, research based on many small (national) reports. An overall picture has then been put together. Investments in production facilities are expensive. Hence, factors such as security, qualified personnel, proximity to the automotive industry, and reliable logistics at the respective locations are important. For these reasons, clustering of investments is consequential. We have identified a few hotspots across Europe for semiconductor production, especially in the Netherlands (Eindhoven), in Germany (Dresden), in Sweden (Gothenburg) and in France (Grenoble). The Centre of Automotive Management (CAM) identified clusters of software development for automated driving that are Munich, Stuttgart, and Paris.

The following table shows the results of the research for investments using a variety of sources.

Table C.5 Data collected on investments in R&D and production of CAD-components

Country	Location	Company	Investment [Mio €2005]	Source
Italy	Agrate	STMicroelectronics	1,285	https://evertiq.com/design/45516; https://www.eetimes.com/st-plans-1-5bn-capex-to-generate-12bn-revenue-in-2020/
Germany	Dresden	Bosch	846	https://www.sueddeutsche.de/wirtschaft/bosch-investitionen-in-mikrochips-1.4630581
Germany	Neubiberg	Infineon Technologies AG	444	ycharts.com
France	Grenoble	Various (Nano 2022)	30	https://www.minatec.org/en/nano-2022-e35-million-earmarked-for-nanotechnology-rd/
Sweden	Göteborg	Zenuity (Autolive+Volvo)	1,296	https://autovistagroup.com/news-and-insights/zenuity-volvo-cars-and-autoliv-joint-venture-starts-operations; https://auto2xtech.com/adas-supplier-veoneer-volvo-split-jv-zenuity-adas/; https://www.veoneer.com/sites/default/files/Veoneer_2019_Annual_Report_on_Form_10K.pdf
Hungary	Budapest	Aimotive	39	https://techcrunch.com/2016/11/15/fully-autonomous-ai-driving-company-aimotive-expands-to-the-u-s/; https://venturebeat.com/2018/01/04/aimotive-raises-38-million-for-self-driving-car-software/
Nether-lands	Amsterdam	STMicroelectronics	1,133	ycharts.com
Nether-lands	Eindhoven	NXP Semiconductors	1,242	ycharts.com
Nether-lands	Duiven	BE Semiconductor	806	ycharts.com
Austria	various	Infineon Technologies AG Austria	30	https://www.infineon.com/dgdl/IFAT+Company+presentation_EN.pdf?fileId=5546d4616463c9cb016465c31f340001

A complete picture on the investments in R&D and production of CAD-components proved difficult to be composed as these investments are specifically related to private business decisions. Data from literature collected is not sufficient yet and therefore assumptions have been performed on the basis of the research and the estimations of domestic turnover of CAD components modelled in the component model.

Within the horizon of the study, investments for EU27 account to almost 50 billion Euro2005. Independent experts rated the estimated size of investments as plausible.

We expect the investments to be made in the first half of the study horizon so that the production facilities are ready on time before the uptake of CAD. The exact timing is scenario dependent and linked to the deployment of SAE level 4 vehicles (2030 for scenarios 1 and 2, 2035 for scenarios 3 and 2040 for scenario 4). For reasons of simplification, a linear cost allocation over 10 years is assumed for the installation with following annual costs for maintenance.

In a further step, these investments are spread across the sectors industrial machines (45%), communications (25%), electronics (20%) and construction (10%) as additional final demand.

Infrastructure investment calculations

The assessment of CAD infrastructure investments involved a desk research in order to define the methodology as well as to obtain cost data, necessary for estimations that are included both in ASTRA as well in NEMESIS for comparison purposes. The individual components can be seen as complex socio-technical (sub-)systems and capital goods with a system life cycle from planning through operation to their decommissioning. For a detailed cost analysis, all system development phases must be taken into account. However, following Protzmann et al. (2018), this analysis uses a simplified distinction between initial costs — such as system design, software development or hardware production — and (yearly) follow-up costs that occur in the usage phase.

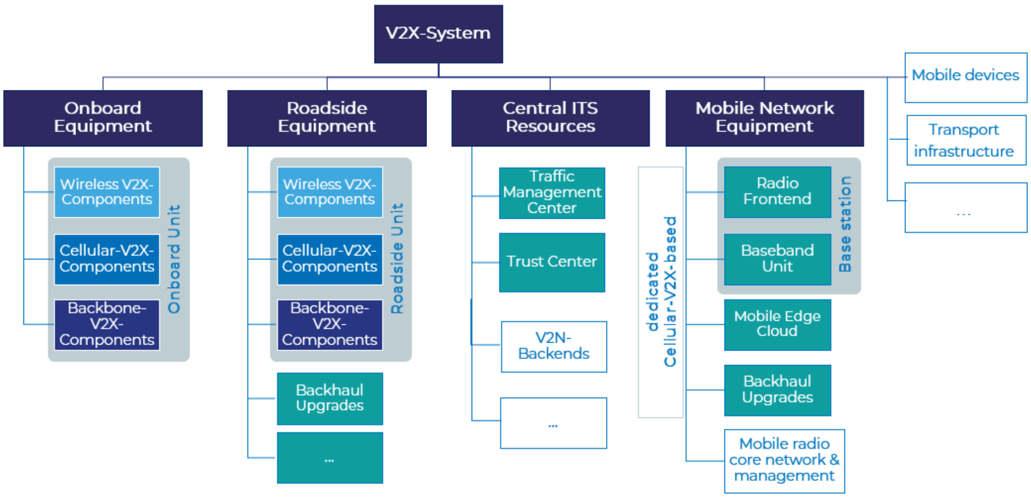
The cost estimation includes assumptions from a variety of relevant sources (in particular Asselin-Miller et al., 2016; C-MobILE Consortium, 2017; Protzmann et al., 2018)[23], which were then verified by the project partners and external experts. A degression of costs — due to the technological development as well as economies related to mass production — is absent in this study for all infrastructure components (not for in-vehicle components).

The development of Cooperative Intelligent Transport Systems (C-ITS) typically involves communication between vehicles (V2V), between vehicles and infrastructure (V2I), vehicle to mobile network (V2N) as well as infrastructure-to-infrastructure (I2I) communication (Asselin-Miller et al., 2016). Following above-mentioned literature, necessary components for a V2X-System were categorized into five types:

- **Onboard (Vehicle) Equipment** fitted by the vehicle manufacturer to enable both V2V communications and V2I along suitably equipped roads;
- **Roadside Equipment** allowing V2I communications along specific stretches of roads;
- **Central ITS (sub-)Systems** in order to manage roadside infrastructure;
- **Personal Devises** such as mobile phones, tablets, personal navigation satnav-type devices that are assumed to enable V2I communications;
- **Mobile Network Equipment.**

[23] Asselin-Miller, N., Biedka, M., Gibson, G., Kirsch, F., Hill, N., White, B., & Uddin, K. (2016). Study on the deployment of C-ITS in Europe: Final Report. Report for DG MOVE MOVE/C, 3, 2014-794.
C-MobILE Consortium. (2017). C-MobILE. Accelerating C-ITS Mobility Innovation and depLoyment in Europe. C-MobILE Consortium, Brussels.
Protzmann, R., Radusch, I., Festag, A., Fritzsche, R., Rehme, M., (2018): IV2X - INTEGRIERTE BETRACHTUNG FAHRZEUGKOMMUNIKATION. In cooperation with / funded by the Senate Department for Economics, Energy and Public Enterprises Berlin. Project number: 141488.

Figure C.7 V2X-subsystems and their components



Source: M-Five based on Protzmann et al. (2018).

Onboard Equipment

Onboard equipment includes the vehicle communication modules to ensure communication with other vehicles and infrastructure equipment along C-ITS equipped roads. In-vehicle devices can either by fitted by the vehicle manufacturer or retrofitted to an old vehicle. Although the costs of individual onboard units (OBUs) will be comparatively low, onboard equipment will make up a significant part of the total system costs due to the very high number of vehicles (C-MobILE Consortium, 2017; Protzmann et al., 2018). To enable C-ITS services, a number of in-vehicle components are required, including transmitter/receivers, antennas, an electronic control unit and additional wiring, some form of display where C-ITS notifications could be presented as well as GPS (Asselin-Miller et al., 2016). In the present analysis, infrastructure investments are treated as investments in components outside the vehicle. The ASTRA vehicle component model covers upfront costs of onboard equipment, whereas the Scenario Model provides ongoing costs of automated vehicles, such as maintenance etc.

Roadside Equipment

The core of the roadside equipment consists of the roadside units (RSUs) integrated in the public traffic space as stationary or quasi-stationary communication nodes, which serve as infrastructure-related counterparts to the onboard units for communication purposes and allow V2I communications along specific roads. RSUs can be equipped with different technology variants — WLAN-V2X, Cellular-V2X, Backend-V2X or combinations of these[24]. The potential locations of RSUs in the transport system are in principle not limited to specific environments. However, it makes sense to use RSUs where information exchange and interactions with traffic engineering facilities, such as traffic light and traffic control systems, can be realized, or on important routes and nodes of the road network with very high traffic flows (Protzmann et al., 2018).

As the integration RSUs in the overall system is significantly complex, Protzmann et al., (2018) classify initial costs into different larger cost blocks that are shown in Figure C.8.

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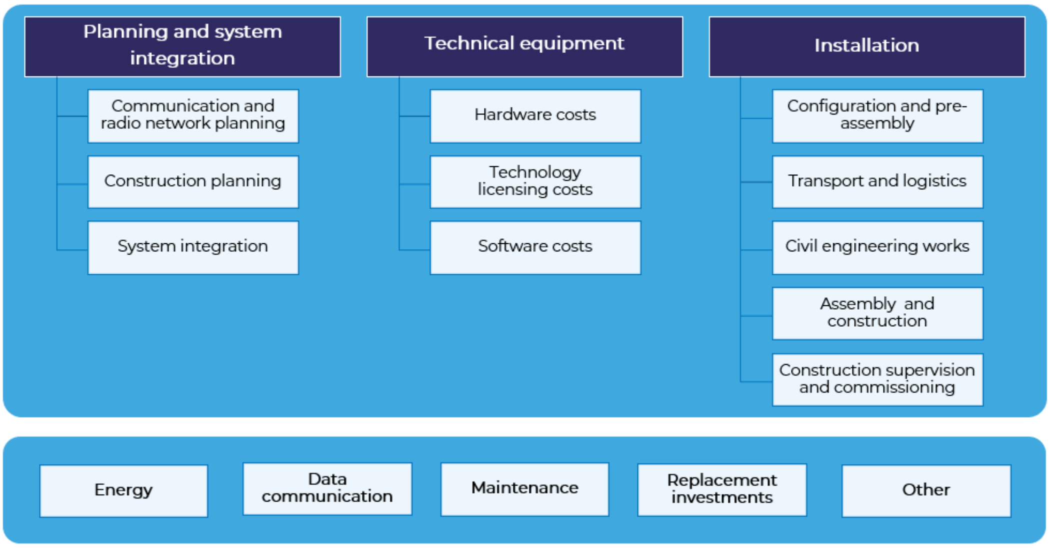
24 WLAN-V2X belongs to the family of communication technologies based on the IEEE 802.11 standard especially for the V2V and V2I communication.
Cellular-V2X: Expansion of mobile radio with functions for vehicle safety; communication between the vehicles and a backend that is mostly on the Internet; expansion expected in the course of the introduction of the 5G standard.
Backend V2X: "conventional" public mobile radio systems and the underlying technologies. The most important extension is the direct communication between end devices, not only between vehicles, but also for the connectivity of RSUs. One of the strengths is the reuse of the existing cellular infrastructure, which reduces installation and operating costs.

Figure C.8 Structure of RSU cost components



Source: M-Five based on Protzmann et al. (2018).

Table C.6 shows the costs per Road-site unit based on the *Basic Scenario* by Protzmann et al. (2018). Initial costs include technical equipment, installation as well as network planning and system integration. Yearly follow-up costs of RSUs typically consist of maintenance costs (for inspection, maintenance and minor repairs), energy costs, and other operating costs. These costs are allocated to the corresponding economic sectors in the model (Construction, Electronics, Energy, Other Market Services, Trade and Repair).

Table C.6 Costs per RSU

Specification	Item	Cost per RSU [EURO 2018]
Initial Costs	Technical Equipment	4,500 €
Initial Costs	Installation	3,000 €
Initial Costs	Network planning and system integration	1,500 €
Follow-up Costs	Maintenance Equipment	338 €
Follow-up Costs	Energy Consumption	53 €
Follow-up Costs	Other Costs (Security, Updates)	250 €

Source: M-Five.

RSU costs can vary greatly depending on the equipment and location. Asselin-Miller et al. (2016) divide roadside ITS sub-systems into two categories: First, upgrades to existing roadside infrastructure (relevant in urban areas only) and second, installation of new roadside units to provide additional coverage. The latter is relevant to inter-urban areas, where the required infrastructure is not already in place. However, this study did not distinguish between those categories. Above shown (basic) cost figures lie in between costs for upgrades of roadsite units and new roadsite sub-systems assumed by Asselin-Miller et al. (2016) and are therefore considered applicable.

By assumption, the RSU density is one RSU every 1 km in accordance with literature (Asselin-Miller et al., 2016). Although most studies assume a lower RSU density, even shorter distances between RSUs may be needed in real-life situations in which the line-of-sight propagation path may be blocked by obstacles such as hills, trees, structures present in the road environment, other vehicles etc. However, the assumption made applies uniformly as an average density and does not differentiate between road category, local conditions and technical parameters of RSUs. RSUs are spread over the relevant Member State specific road network including motorways, main or national roads, secondary or regional roads and other relevant roads based on Transport in Figures (EC DG MOVE, 2019)[25]. The rollout is assumed to take 10 years and lifetime exceeds the study horizon of 2050, i.e. no replacement is modelled.

Backhaul Upgrade

RSUs require a backhaul connection that is sufficient for their intended use (e.g. via fiber optics) as well as suitable interfaces (modules) to their control units if they are linked to traffic systems. It can be expected that backend V2X will often be the most practical solution for the backhaul connection of RSUs if there is not yet sufficient access to wired networks (Protzmann et al., 2018). Backhaul network costs are assumed to be 19,000€/km based on the *Breaking Scenario* of EC DG CNECT (2020)[26].

Central Intelligent Transport System (ITS) Resources

A central ITS transport system is needed to connect roadside sub-systems to a centralized system, where data can be analysed in order to facilitate effective traffic management and the deployment of V2I services. Asselin-Miller et al. (2016) define Central ITS sub-systems *"as the back-office systems and software required to link roadside infrastructure and individual user applications to centralised traffic management centre (TMC) and local controller interfaces"* (Asselin-Miller et al., 2016, p.17). Traffic management centres, trust centres to guarantee security and privacy requirements and application-specific centres for new types of special applications are essential central subsystems that are able to manage services for an entire city, a road operator or national highway system (Protzmann et al., 2018).

Initial costs include investments in new software solutions as well as in central hardware resources and infrastructures. Follow-up costs accrue for software maintenance, operating costs for hardware and infrastructure (e.g. energy and maintenance costs, rents, insurance, data communication costs) and administrative costs (Protzmann et al., 2018).

In this study, central ITS sub-system costs are considered on Member State level. Following Asselin-Miller et al. (2016), it is assumed that roadside ITS sub-systems will be integrated into existing TMCs. Subsequently, initial costs of central ITS resources only refer to TMC integration costs to connect RSUs and local traffic controller with TMCs both in urban as well as inter-urban areas. (Yearly) ongoing costs include back office operations and maintenance and application development costs. All costs are allocated to the relevant economic sectors. The lifetime of the TMC integration is assumed to exceed the modelling horizon.

Table C.7 Costs of Central Intelligent Transport System Integration

Specification	Item	Costs per Country [EURO 2015]
Initial Costs	Integration of RSU into TMC (urban & inter-urban)	3,000,000 €
Initial Costs	Interface from RSU to local traffic controller (urban & inter-urban)	2,000,000 €
Follow-up Costs	Back Office Operation and Maintenance	500,000 €
Follow-up Costs	Application Development Costs	600,000 €

Source: M-Five.

25 European Commission. Directorate-General for Mobility and Transport. (2019). EU Transport in Figures: Statistical Pocketboook. Office for official publications of the European communities.

26 European Commission. Directorate-General for Communications Networks, Content & Technology. (2020). Supporting the implementation of CEF2 Digital - SMART 2017/0018. Final Report. Office for official publications of the European communities.

It is evident, that the need for expansion in traffic management centres is heavily dependent on the existing systems and technologies in the respective traffic area. In addition, each EU Member State operates with different road traffic standards and protocols. The approach described includes the assumption that the functionalities of the central ITS systems can be carried out by existing traffic management centres. This is a workable assumption on the TEN-T road network, but may not be appropriate for other parts of the road network. Urban regions and cities as well as interurban and rural road networks are not comprehensively equipped with traffic management centres. Alternatively, the support functions of automated driving may be organised in different ways. For example, private service provider may implement them as an outsourced service, or a new public sector organisation may be established. Some considerable new investments and higher follow-up costs are to be expected. However, since quantifying infrastructure costs is subject to great uncertainties and this study makes estimations on Member State level, a differentiation between areas with and without TMCs is not feasible. The cost estimate here is obviously rather low due to the limitations mentioned above.

Mobile Network Equipment

The Mobile Network Equipment represents the technical-infrastructural basis of the public cellular mobile network. Although adequate network implementation is a prerequisite for CAD, we have not integrated it fully into the actual modelling as it serves many other purposes besides transport issues and CAD only represents one of countless applications. Backhaul network costs are estimated as outlined above. Further, connectivity along the main traffic axes is particularly demanding and less relevant for other sectors. For this reason, a (partial) investment in the mobile network is attributed to the transport sector. These costs account for 70,000€/km highway based on the Breaking Scenario for a 5G cellular network of EC DG CNECT (2020).

Personal ITS sub-systems

Personal ITS sub-systems enable V2I communications along suitably equipped roads. In the future, these devices may also enable V2V communications (Asselin-Miller et al., 2016). As users' mobile devices such as navigation devices, smartphones, tablets, wearables, etc. or will exist anyway regardless of certain implementation scenarios, these elements are not considered in CAD infrastructure investments.

Rollout and Implementation

The rollout of infrastructures components is scenario dependent. The timing of completing the necessary infrastructure is linked to the deployment of SAE level 4 vehicles (2030 for scenarios 1 and 2, 2035 for scenarios 3 and 2040 for scenario 4). A further in-depth linkage between the infrastructure costs and the level of automations is not modelled in this study. It is assumed that a full implementation of CAD-infrastructure takes 10 years and that cost allocation is linear. Annual ongoing costs in the construction phase are incurred as share of the expansion. The assumed lifetime (maximum operating time 20 years) exceeds the horizon of the study, so that no renewal of infrastructure components is modelled.

A differentiation according to operational design domains (e.g. weather conditions and types of road infrastructure in which the automated vehicle is supposed to operate) is not feasible in the context of this study, which covers EU27. Other studies that examine small, isolated areas include specific cost items, for example studies by Protzmann et al. (2018) for Berlin or Kulmala et al. (2018) for Finland considering super active snow-removal.

Total Costs

These numbers are explicitly treated as investment in the models. According to economic theory, they have to be financed by any stakeholder on the other side. Private and commercial vehicle buyers will fundamentally bear the onboard equipment costs. Roadside equipment subsystems as well as traffic management centres involve great uncertainty as to which stakeholders can and will finance which costs. Public authorities as well as private sector stakeholders (content and service operators, automobile manufacturers, etc.) have both reasons for participating in financing components. It is possible that they are also refinanced through forwarding costs to the customers. For simplification, it is assumed that costs will be borne by the end users of CAD. These considerations are covered by assumptions and key figures of the Scenario Model that are passed on to ASTRA and NEMESIS.

In Sum, initial investment (installation over 10 years) at EU27 level is approximately 140 billion EURO2005. Yearly follow-up investment is nearly 3 billion EURO2005 at EU27 level. Depending on scenario, total costs from 2020 to 2050 are between 184 to 208 billion EURO2005.

Again, these costs do cover neither necessary network investments, on-board equipment, personal devises nor investments in the largely existing traffic infrastructure (traffic signal and traffic control systems, traffic control centres, stationary sensors, etc.).

The annual investments are in the range of the different scenarios of the “Study on the deployment of C-ITS in Europe” by Asselin-Miller et al. (2016), who also estimates total costs of approximately 3 billion euros for the year 2030 at EU-level. Further, independent experts have confirmed the order of magnitude of initial as well as annual investment based on the assumptions made.

The numbers are to be understood as literature based, initial assessment, but not as predictions with high forecasting quality and, from today's perspective, are subject to a very high degree of uncertainty. Different scenarios with large cost ranges appear possible.

The Nemesis Model

NEMESIS is a detailed macro sectoral simulation model for the EU economy. It includes all EU Member States, which can be simulated altogether or individually. The rest of the world is not explicitly modelled, but the model allows a simplified modelling of the external trade of EU with the other world regions that are regrouped as follows: Australia, Brazil, Canada, Switzerland, China, India, Indonesia, Japan, South Korea, Mexico, Norway, Russia, Turkey, Taiwan, USA and other.

There are 30 production sectors of which one sector for agriculture, 6 utilities, 13 manufacturing industries, construction, 3 transport services industries, 6 groups of market services and non-market services. Table C.1 provides an overview of the different sectors in the NEMESIS model, the ASTRA model and the corresponding NACE sectors.

NEMESIS with its level of detail requires a large consolidated database for its functioning. Data are compiled from numerous sources and are post-processed for ensuring their whole accounting coherency. The main economic variables such as production, value added or employment are coming from Eurostat National Accounts and Labour force survey (Eurostat, 2017a, 2017b). Trade data are based on WIOD (Timmer *et al.,* 2015) and fiscal data are derived from DG TAXUD datasets (DG TAXUD, 2017a, 2017b).

The baseline scenario model is based, on a set of exogenous variables (demography, world demand, oil price, exchange rates, etc.) and economic projections similar to DG ECFIN 2016 ageing report. This baseline scenario was designed for every EU country at a detailed sectoral level

(30 sectors) and it provides results on production, employment, revenues, and competitiveness indicators at the macro and sectoral levels up to 2050.

This choice imposes therefore strong constraints on the NEMESIS model, where the calculus of GDP is at the same time (1) the addition of its different aggregated components: public and private final consumption, total investment and net exports (exportations minus importations), and (2) the aggregation of the added values of the 30 production sectors that are included in the model. As, except for the short term (up to 2018), the DG ECFIN forecasts don't provide projections for the GDP counterparts, as it neither produce forecasts at sectoral level, the original contribution of NEMESIS for this forward-looking exercise in therefore to produce its own figures, for all the other variables than GDP. These include projections for GDP counterparts, sectoral evolutions (production, value-added, exports, imports, employment per skill, etc.) and numerous other indicators as unemployment rates, energy consumption and CO_2 related GHG emissions, this, for every countries and sectors represented in the model.

The Synthesis Model

This section includes the different components of the synthesis model.

Multi-layer approach (sectors, services, synthesis)

The quantitative impacts of the four CAD scenarios (see Annex B) on the labour market are presented in this annex by focusing on three layers analysed by this project.

Layer 1 provides sectoral results at the aggregate level of EU27 as well as at Member States level. The economic models consider 25 NACE[27] sectors in terms of ASTRA and 30 NACE sectors in terms of NEMESIS. The results are presented for five CAD-related sectors: vehicles, electronics, computers, communication and construction.

For layer 2, results are presented differentiating the job impacts due to changes in mobility services for freight and passenger transport. Road freight transport is sub-divided into light-duty vehicles (up to 3.5 tonnes total weight) and heavy-duty vehicles (more than 3.5 tonnes total weight). Passenger transport is sub-divided into buses (classic and automated), taxi operations (classic and automated) as well as car and ridesharing. The results differentiate between impacts on drivers and non-driver job categories. At this stage, the non-driver category remains aggregated.

Layer 3 provides spatial results on the level of NUTS[28] II zones within EU27 as well as UK, Norway and Switzerland. These results differentiate between domestic regions (NUTS II zones) and job categories. In distinction to layer 2, the job category "non-driver" is divided into six sub-categories: administration, management, IT, customer service, stewards & operation staff and maintenance. Finally, the national and service-based numbers are disaggregated for every job category and NUTS II zone.

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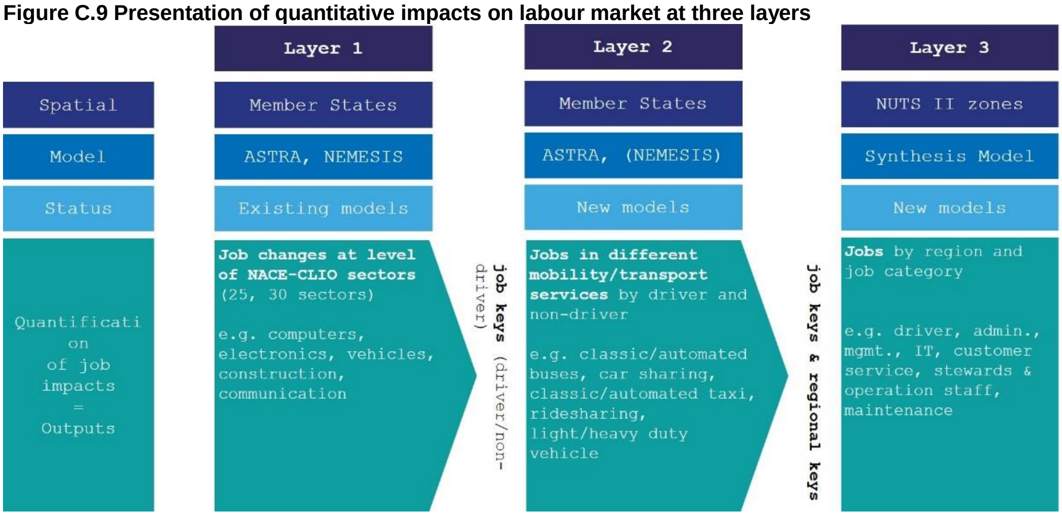
[27] NACE = Statistical Classification of Economic Activities in the European Community. The classification applied is an extended version used to elaborate input-output tables for EU MS, which covers additional manufacturing sectors compared with NACE level 1 rev. 2 from 2008.

[28] NUTS = Nomenclature of Territorial Units for Statistics. The geocode standard refers to the subdivisions of countries for statistical purposes. The standard is developed and regulated by the European Union and covers the EU MS in detail.

Figure C.9 Presentation of quantitative impacts on labour market at three layers



Source: Consortium.

The approaches presented above, **the occupational and spatial breakdown**, are elaborated by the ASTRA-EU model and updated to include CAD-relevant developments and scenario model inputs.

Approach of job keys (occupational breakdown)

The development of the job keys was carried out to build a disaggregated framework for the distribution of service-based job numbers in different job categories. For this purpose, we calculated percentages of job categories by every MS and service. The percentages are based on literature and own variation (in cases where no direct sources were available). To include differentiations also in cases of data gabs, we define three CAD progress profiles based on the different development in terms of CAD. Depending on the national situation in terms of CAD development, every MS was assigned to one of three profiles:

- Countries whose CAD development is expected to be fast and innovative in relation to other European countries (profile “progressive”);
- Countries whose CAD development is expected to be moderate and rather cautious in relation to other European countries (profile “average”);
- Countries whose CAD development is expected to be slow and behind other European countries (profile “lagging”).

This assignment is based on the groups of forerunner countries in the four scenarios (see annex B) but also on a global ranking of countries in KPMG’s *2019 Autonomous Vehicles Readiness Index* and other sources (KPMG, 2019)[29]. Where no particular deviations upwards or downwards were noticeable, we assigned the MS to the profile “average”. As a result, we assigned eight countries to the profile “progressive”, thirteen countries to the profile “average” (with constraints in case of Switzerland)[30] and nine countries to the profile “lagging” (see Table C.8).

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29 KPMG (2019): Autonomous Vehicles Readiness Index - Assessing countries’ readiness for autonomous vehicles. KPMG International, online: https://home.kpmg/xx/en/home/insights/2019/02/2019-autonomous-vehicles-readiness-index.html.

30 Because the long-time forerunner status of the public transport and car sharing market in Switzerland, we assigned the country to the CAD profile “progressive” (only in terms of classic and automated bus as well as car sharing).

Table C.8 CAD progress profiles in terms of MS

Country	CAD profile	References of "profiling"
AT	average	high position in the CAD Readiness Index by KPMG (rank 16 of 25)
BE	average	partly scenario-forerunner but not in den CAD Readiness Index by KPMG
BG	lagging	neither in scenario forerunner groups nor in CAD Readiness Index by KPMG
CH	average	no particular deviations upwards or downwards noticeable, exception: bus (classic/automated) and car sharing
CY	lagging	neither in scenario forerunner groups nor in CAD Readiness Index by KPMG
CZ	average	part of CAD Readiness Index by KPMG but low position (rank 19 of 25)
DE	progressive	part of scenario forerunner groups and high position in CAD Readiness Index by KPMG (8/25)
DK	progressive	partly in scenario forerunner groups
EE	average	no particular deviations upwards or downwards noticeable
EL	lagging	neither in scenario forerunner groups nor in CAD Readiness Index by KPMG
ES	average	partly in scenario forerunner groups and low position in CAD Readiness Index by KPMG (rank 18 of 25)
FI	progressive	part of scenario forerunner groups and high position in CAD Readiness Index by KPMG (rank 6 of 25)
FR	average	low position CAD Readiness Index by KPMG (rank 17 of 25)
HR	lagging	neither in scenario forerunner groups nor in CAD Readiness Index by KPMG
HU	average	part of CAD Readiness Index by KPMG but low (rank 21 of 25)
IE	average	no particular deviations upwards or downwards noticeable
IT	lagging	neither in scenario forerunner groups nor in CAD Readiness Index by KPMG
LT	average	no particular deviations upwards or downwards noticeable
LU	progressive	strong economy, good test site conditions
LV	average	no particular deviations upwards or downwards noticeable
MT	average	no particular deviations upwards or downwards noticeable
NL	progressive	part of scenario forerunners and top position in CAD readiness index by KPMG (rank 1 of 25)
NO	progressive	part of scenario forerunners and high position in CAD readiness index by KPMG (rank 3 of 25)
PL	average	no particular deviations upwards or downwards noticeable
PT	lagging	neither in scenario forerunner groups nor in CAD Readiness Index by KPMG
RO	lagging	neither in scenario forerunner groups nor in CAD Readiness Index by KPMG
SE	progressive	part of scenarios forerunner groups and high rank in CAD Readiness Index by KPMG (rank 5 of 25)
SI	lagging	neither in scenario forerunner groups nor in CAD Readiness Index by KPMG
SK	lagging	neither in scenario forerunner groups nor in CAD Readiness Index by KPMG
UK	progressive	partly scenarios forerunner groups and high rank in the CAD Readiness Index by KPMG (rank 7 of 25)

Source: M-Five.

The job shares (percentages) for the three profiles were varied according to the three dates of the timescale in this project, which are the years 2025 (short-term), 2040 (mid-term) and 2050 (long-term). The following matrix was created for every service (see Table C.9).

Table C.9 Framework of the generic job keys (general framework)

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
Status quo								
Progressive	%	%	%	%	%	%	%	100%
Average	%	%	%	%	%	%	%	100%
Lagging	%	%	%	%	%	%	%	100%
2025								
Progressive	%	%	%	%	%	%	%	100%
Average	%	%	%	%	%	%	%	100%
Lagging	%	%	%	%	%	%	%	100%
2040								
Progressive	%	%	%	%	%	%	%	100%
Average	%	%	%	%	%	%	%	100%
Lagging	%	%	%	%	%	%	%	100%
2050								
Progressive	%	%	%	%	%	%	%	100%
Average	%	%	%	%	%	%	%	100%
Lagging	%	%	%	%	%	%	%	100%

Source: M-Five.

As we used the same job categories for all services (passenger and freight transport), every category includes several kinds of jobs. We tried to find main-categories with similar requirements and salary levels. The following table shows the main-categories and the most important sub-categories (see Table C.10).

Table C.10 categories of the job key distribution

Job categories		
Job key *general* (Layer 2)	Job key *detail* (Layer 3)	Job / tasks (selection)
Driver	Driver	-
Non-Driver	Administration	• controlling; • human resources; • secretariat.
	Management	
	IT	• operators; • engineers.
	Customer Service	• dispatcher; • ticket sales; • call centre; • marketing; • miscellaneous.
	Steward & operation support	• logistics / warehousing; • bus/train attendant; • security personnel; • station attendant (bus); • logistics handlers; • cleaning staff.

Job categories		
Job key *general* (Layer 2)	Job key *detail* (Layer 3)	Job / tasks (selection)
	Maintenance	• maintenance (without cleaning); • repairing.

Source: M-Five.

The following sections describe the approaches for the different services.

Bus (classic, SAE level 1-4)

The split between drivers and non-drivers is based on a collection of data of public transport associations and companies. The data set was made available to M-Five by the project's internal stakeholders UITP and IRU and was supplemented by M-Five's own online research. Employment data was available for several hundred companies from numerous EU MS. For some of them, the percentage of drivers was available. The data set was assigned to the three CAD progress profiles mentioned above (progressive, average and lagging).

The split within the non-driver is based on data of three countries. Data from the Association of German Transport Companies (VDV) covering three different job categories: driving staff, technical staff and administration staff (the distribution in terms of the additional categories is based on own assumptions). We take the German split for the countries with the profile "progressive". Non-driver splits were also available for two other countries: France and Spain. The average of these splits is the basis for the profile "average" (according to the attribute of both countries). The split of the third profile, "lagging", is based mainly on own assumption but oriented on the other generic splits. In relation to countries with the profile "progressive" and "average", we expect lower percentages for IT jobs while the percentages for customer service, stewards, maintenance jobs will be lower because of less automation/connectivity and therefore less economic efficiency. Table C.11 shows the job keys of the service "bus classic".

Table C.11 job keys for buses (classic)

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
Status quo								
Progressive	48%	8%	2%	10%	11%	4%	17%	**100%**
Average	58%	5%	2%	7%	8%	8%	12%	**100%**
Lagging	51%	7%	2%	5%	11%	7%	17%	**100%**
2025								
Progressive	48%	8%	2%	11%	11%	3%	17%	**100%**
Average	58%	5%	2%	8%	8%	7%	12%	**100%**
Lagging	51%	7%	2%	5%	11%	7%	17%	**100%**
2040								
Progressive	48%	8%	2%	15%	10%	2%	15%	**100%**
Average	58%	5%	2%	12%	7%	6%	10%	**100%**
Lagging	51%	7%	2%	10%	10%	5%	15%	**100%**
2050								
Progressive	48%	8%	2%	18%	9%	1%	14%	**100%**
Average	58%	5%	2%	15%	6%	5%	9%	**100%**
Lagging	51%	7%	2%	13%	9%	4%	14%	**100%**

Source: M-Five.

Robo-Bus (automated, SAE Level 5)

Due to the lack of statistical percentages for robo-buses[31], the shares of jobs in this service are based mainly on own assumptions but oriented on pilot projects. As these projects include very limited fleets and staffs, the aspect of *economics of scale* can only be calculated on a generic basis. On the one hand we add percentages of IT staff in 2040 and 2050 for the profile "progressive" and "average" as well as partly for the profile "lagging" (here only for the year 2050). On the other hand, we see less steward and maintenance because of progress in automation/connectivity of traffic technologies. A main assumption is that these buses do not need any driver in a common sense. Instead of traditional drivers, they need a broader staff of stewards which can also overtake the manual control in special situations like technical failures and in case of untypical traffic or weather conditions. Therefore, we set the shares of driver to zero percent but increased the share for the job category "stewards and operation staff" on a level higher than 50 % (with reductions for 2040 and 2050 especially in the profile "progressive"). Table C.12 shows the job keys of the service "robo-bus".

Table C.12 job keys for buses (automated)

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
				Status quo				
Progressive	0%	6%	2%	10%	10%	60%	12%	**100%**
Average	0%	6%	2%	10%	10%	60%	12%	**100%**
Lagging	0%	6%	2%	10%	10%	60%	12%	**100%**
				2025				
Progressive	0%	6%	2%	10%	10%	60%	12%	**100%**
Average	0%	6%	2%	10%	10%	60%	12%	**100%**
Lagging	0%	6%	2%	10%	10%	60%	12%	**100%**
				2040				
Progressive	0%	6%	2%	22%	10%	50%	10%	**100%**
Average	0%	6%	2%	15%	10%	57%	10%	**100%**
Lagging	0%	6%	2%	10%	10%	60%	12%	**100%**
				2050				
Progressive	0%	6%	2%	39%	10%	33%	10%	**100%**
Average	0%	6%	2%	27%	10%	45%	10%	**100%**
Lagging	0%	6%	2%	22%	10%	50%	10%	**100%**

Source: M-Five.

Taxi (classic, SAE level 1-4)

The job keys for the common taxi market is based on the results of a report written on behalf of the European Commission (DG Move) in 2016 (Frazzani et al., 2016)[32]. The percentages of driver and non-driver are largely taken from this study. The splits for the non-driver job categories (status quo) are oriented on educated guesses from a representative of the German taxi and rental car association (*Bundesverband Taxi und Mietwagen*, bzp). On this basis as well as on study results and stakeholder statements, the job key for the future (2025, 2040 and 2050) follows own assumptions. In our perspective – with the study results in mind – the percentages of the IT staff will increase while the maintenance staff will be decrease. The biggest share, which is the driver job, will remain on today's level. The reason is the definition of classic taxi as vehicles with a maximum SAE level of 3. This means that a professional taxi driver will still be necessary in all CAD

[31] According to our definition, a driverless bus is not limited in size or scope. It includes both urban public transport and inter-city coaches. The SAE level is 4 or 5.

[32] Frazzani, Simona; Grea, Gabriele, Zamboni, Alessandro (2016): Study on passenger transport by taxi, hire car with driver and ridesharing in the EU – Final Report. Available on https://ec.europa.eu/transport/sites/transport/files/2016-09-26-pax-transport-taxi-hirecar-w-driver-ridesharing-final-report.pdf.

progress profiles ("progressive", "average", "lagging") and in all years (2025, 2040, 2050). Table C.13 shows the job keys of the service "taxi classic".

Table C.13 job keys for taxi (classic)

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
				Status quo				
Progressive	56%	4%	16%	0%	7%	1%	16%	**100%**
Average	54%	4%	16%	0%	7%	1%	18%	**100%**
Lagging	54%	5%	16%	0%	7%	0%	18%	**100%**
				2025				
Progressive	56%	4%	15%	3%	7%	1%	14%	**100%**
Average	54%	4%	16%	1%	7%	1%	17%	**100%**
Lagging	54%	5%	16%	1%	7%	0%	17%	**100%**
				2040				
Progressive	56%	4%	15%	10%	6%	1%	8%	**100%**
Average	54%	4%	16%	5%	6%	1%	14%	**100%**
Lagging	54%	5%	16%	3%	6%	0%	16%	**100%**
				2050				
Progressive	56%	4%	15%	13%	7%	1%	4%	**100%**
Average	54%	4%	16%	8%	4%	1%	13%	**100%**
Lagging	54%	5%	16%	5%	6%	0%	14%	**100%**

Source: M-Five.

Robo-Taxi (automated, SAE level 5)

As currently no representative/empirical basis of job shares for robo-taxis[33] exists, we used completely educated guesses and own assumptions. Although these taxis will operate with SAE level 5, we assume that some, but only low, percentages of driver staff will be necessary. In contrast to robo-buses (see above), we do not expect increase of stewards which is an unusual job category for taxi operations. Therefore, we keep a low percentage of professional drivers, even in 2040 and 2050, for controlling the taxi in special situations like technical failures as well as in case of untypical traffic or weather conditions. Of course, the job characteristics of this new "taxi driver" will not be the same as today. Therefore the percentages alone cannot explain all these qualitative characteristics. The distribution of non-driver job categories was calculated in direct relation to the split of non-drivers in taxis with lower SAE levels (see "taxi classic"). For the years 2040 and 2050, we made some manual changes in terms of management (lower than today) and IT (higher than today) because of efficiency increases in the operations of taxi fleets. Table C.14 shows the job keys of the service "robo-taxi".

[33] According to our definition: Similar to a traditional taxi a robo-taxi transporting single passengers or groups of passengers with a common destination, but the vehicles operates with SAE level 4 and 5.

Table C.14 job key for taxi (automated)

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
				Status quo				
Progressive	25%	7%	27%	0%	11%	2%	28%	**100%**
Average	25%	7%	26%	0%	11%	1%	30%	**100%**
Lagging	25%	7%	26%	0%	11%	1%	30%	**100%**
				2025				
Progressive	20%	8%	28%	5%	12%	2%	25%	**100%**
Average	20%	8%	28%	2%	12%	1%	29%	**100%**
Lagging	20%	8%	28%	2%	12%	1%	29%	**100%**
				2040				
Progressive	5,0%	9%	28%	27%	12%	2%	17%	**100%**
Average	5,0%	9%	31%	13%	12%	1%	29%	**100%**
Lagging	5,0%	9%	33%	7%	12%	1%	33%	**100%**
				2050				
Progressive	1%	10%	30%	34%	14%	2%	9%	**100%**
Average	1%	10%	32%	20%	8%	1%	28%	**100%**
Lagging	1%	10%	34%	12%	12%	1%	30%	**100%**

Source: M-Five.

Car sharing

The job keys of the car sharing services are based on different sources: On the one hand, we asked an expert with many years of consulting experience in this market. He explained us the main job categories in this sector and the typical percentages in general sense (without outsourcing, which is too specific). On the other hand, we used case studies of a report about car sharing business models which simulated job structures for the future. As a result, we built an overall non-driver split which we varied according to the three CAD progress profiles ("progress", "average", "lagging") and the different years (2025, 2040, 2050). The driver category is always zero percent because in the definition of car sharing the users drive the cars by their own. Therefor we defined car sharing vehicles as cars which have SAE level 3 or lower. Similar services with higher SAE level are covered by the service *robo-taxi* (see above). Table C.15 shows the job keys of the service "car sharing".

Table C.15 job keys for carsharing

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
Status quo								
Progressive	0%	18%	2%	15%	20%	10%	35%	**100%**
Average	0%	18%	2%	15%	20%	10%	35%	**100%**
Lagging	0%	18%	2%	15%	20%	10%	35%	**100%**
2025								
Progressive	0%	18%	2%	15%	20%	10%	35%	**100%**
Average	0%	18%	2%	15%	20%	10%	35%	**100%**
Lagging	0%	18%	2%	15%	20%	10%	35%	**100%**
2040								
Progressive	0%	18%	2%	33%	20%	10%	17%	**100%**
Average	0%	18%	2%	25%	20%	10%	25%	**100%**
Lagging	0%	18%	2%	20%	20%	10%	30%	**100%**
2050								
Progressive	0%	18%	2%	40%	20%	10%	10%	**100%**
Average	0%	18%	2%	33%	20%	10%	17%	**100%**
Lagging	0%	18%	2%	25%	20%	10%	25%	**100%**

Source: M-Five.

Ridesharing

Similar to other services, which do not currently exist in a broader sense – like automated buses for instance – we do not have much job data for ridesharing. Nevertheless, some start-ups like the German brand *Clever Shuttle* shows first indicators for job structures in this sector. On this quite small basis, we built up our job keys for future ridesharing service. Some categories, like cleaning or administration, seem to be similar to common taxi operations. The sub-task “cleaning” is covered by the job category “stewards and operation staff” (see Table C.10). Since we defined ridesharing as a shared automated taxi (SAE level 5) picking up various passengers with various destinations, we did not divide this service into a conventional and an automated variant. Despite of this definition we calculated also large job shares in the driver categories for status quo and in 2025 because at this stage, vehicles with level 5 are not yet in the market. In 2040 and 2050, the job category “stewards and operation staff” includes, besides cleaning etc., a significant proportion of special stewards who can take over the control of the vehicle when necessary. However, for technical disposition journeys (operational purposes) or in sensitive areas with high safety regulations, we have included some percentages of professional drivers, too. Table C.16 shows the job keys for the service “ridesharing”.

Table C.16 job keys for ridesharing

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
				Status quo				
Progressive	60%	4%	2%	5%	8%	1%	20%	**100%**
Average	60%	4%	2%	5%	8%	1%	20%	**100%**
Lagging	60%	4%	2%	5%	8%	1%	20%	**100%**
				2025				
Progressive	55%	4%	2%	10%	6%	3%	20%	**100%**
Average	55%	4%	2%	10%	6%	3%	20%	**100%**
Lagging	55%	4%	2%	10%	6%	3%	20%	**100%**
				2040				
Progressive	10%	5%	2%	30%	5%	25%	23%	**100%**
Average	10%	5%	2%	25%	5%	30%	23%	**100%**
Lagging	10%	5%	2%	20%	5%	35%	23%	**100%**
				2050				
Progressive	5%	5%	2%	33%	5%	30%	20%	**100%**
Average	5%	5%	2%	27%	5%	36%	20%	**100%**
Lagging	5%	5%	2%	22%	5%	41%	20%	**100%**

Source: M-Five.

Light-duty vehicle (classic, SAE Level 1-3)

The job keys for common LDVs are based on a publication of the German Federal Association for Parcel and Express Logistics (BIEK, 2016)[34] which contains percentages for the typical job categories in this sector (administration, driving, IT and warehousing). The shares for administration were distributed between our categories “administration”, “management” and “customer service”. As this service category is defined as non-automated (SAE level 1-3), we take the current driver share for all generic groups (progress, average, lagging) and dates (2025, 2040, 2050). Adjustments were made in case of IT staff (a lot of staff in the future especially in the progressive and partly in the average CAD progress profile in 2040 and 2050) as well as in warehousing (less staff because of automation within logistics). Table C.17 shows the job keys of the service “classic light-duty vehicle”.

[34] BIEK (2016): KEP-Studie 2016 – Analyse des Marktes in Deutschland. Bundesverbandes Paket und Expresslogistik e. V., available on https://www.biek.de/download.html?getfile=150.

Table C.17 job keys for light-duty vehicles (classic)

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
Status quo								
Progressive	51%	3%	1%	2%	3%	38%	2%	**100%**
Average	51%	3%	1%	2%	3%	38%	2%	**100%**
Lagging	51%	3%	1%	1%	3%	38%	3%	**100%**
2025								
Progressive	51%	3%	1%	4%	3%	36%	2%	**100%**
Average	51%	3%	1%	3%	3%	37%	2%	**100%**
Lagging	51%	3%	1%	2%	3%	38%	2%	**100%**
2040								
Progressive	51%	3%	1%	15%	3%	25%	2%	**100%**
Average	51%	3%	1%	10%	3%	30%	2%	**100%**
Lagging	51%	3%	1%	5%	3%	35%	2%	**100%**
2050								
Progressive	51%	3%	1%	20%	3%	20%	2%	**100%**
Average	51%	3%	1%	15%	3%	25%	2%	**100%**
Lagging	51%	3%	1%	10%	3%	30%	2%	**100%**

Source: M-Five.

Light-duty vehicle (automated, SAE Level 4 & 5)

Due to lack of data availability for the employment of automated/driverless light-duty vehicles, the driver share is based on own assumptions oriented towards the scenario outputs, interview evaluation and other research results. The non-driver categories were calculated in direct relation to the correspondent categories of common LDV (see above). For the years 2040 and 2050, we used the same job key for every CAD progress profile (“progressive”, “average” and “lagging”) because we had little evidence for differentiation, as the development of automated/driverless LDV lay mainly in the far future (2040 and behind). Moreover, we assume, that all countries start more or less at the same level, because the knowledge transfer among the EU member states should be higher than in early decades for conventional traffic technologies. Table C.18 shows the job keys of the service “automated light-duty vehicle”.

Table C.18 job keys for light-duty vehicles (automated)

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
Status quo								
Progressive	25%	5%	2%	23%	5%	38%	3%	**100%**
Average	25%	5%	2%	23%	5%	38%	3%	**100%**
Lagging	25%	5%	2%	22%	5%	38%	5%	**100%**
2025								
Progressive	20%	5%	2%	29%	5%	37%	3%	**100%**
Average	20%	5%	2%	28%	5%	37%	3%	**100%**
Lagging	20%	5%	2%	27%	5%	38%	3%	**100%**
2040								
Progressive	5%	6%	2%	40%	6%	37%	4%	**100%**
Average	5%	6%	2%	40%	6%	37%	4%	**100%**
Lagging	5%	6%	2%	40%	6%	38%	4%	**100%**
2050								
Progressive	1%	6%	2%	50%	6%	30%	4%	**100%**
Average	1%	6%	2%	50%	6%	31%	4%	**100%**
Lagging	1%	6%	2%	50%	6%	31%	4%	**100%**

Source: M-Five.

Heavy-duty vehicle (classic, SAE Level 1-3)

The job keys for Heavy-Duty Vehicles are based on an own empirical survey: M-Five asked logistic companies of different size (from 30 vehicles up to 800 vehicles) about current employment shares (percentages of jobs) using the same framework as we used for the internal calculation. Additionally, we included statistical data of the German Road Freight Transport Association (*Bundesverband Güterkraftverkehr, BGL*). The average of all these keys – company and statistical data – was varied according to our CAD progress profiles mentioned above (progressive, average, lagging) as well as the timing (2025, 2040, 2050). As we define this service as conventional (SAE level 3 or lower), we made no significant changes in the percentages for driver. Within the non-driver spilt, we made some adjustments regarding IT (higher than today) and maintenance (lower than today). Table C.19 shows the job keys of the service “classic heavy-duty vehicle”.

Table C.19 job keys for heavy-duty vehicle (classic)

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operate.	Maint.	TOTAL
Status quo								
Progressive	73%	7%	2%	1%	3%	7%	7%	100%
Average	73%	7%	2%	1%	3%	7%	7%	100%
Lagging	73%	7%	2%	1%	3%	7%	7%	100%
2025								
Progressive	73%	7%	2%	3%	3%	6%	6%	100%
Average	73%	7%	2%	3%	3%	6%	6%	100%
Lagging	73%	7%	2%	3%	3%	6%	6%	100%
2040								
Progressive	73%	6%	2%	7%	3%	4%	5%	100%
Average	73%	6%	2%	7%	3%	4%	5%	100%
Lagging	73%	6%	2%	7%	3%	4%	5%	100%
2050								
Progressive	73%	5%	2%	10%	3%	3%	4%	100%
Average	73%	5%	2%	10%	3%	3%	4%	100%
Lagging	73%	5%	2%	10%	3%	3%	4%	100%

Source: M-Five.

Heavy-duty vehicle (automated, SAE Level 4 & 5)

Due to lack of data availability for the employment of automated/driverless trucks, the driver share is based on own assumptions oriented towards the scenario outputs, interview evaluation and other research results. The non-driver categories were calculated in direct relation to the correspondent categories for common HDV. For this service, we use the same job key for every CAD progress profile (progressive, average and lagging), because we assume an EU wide road freight transport market without a clear relation to individual countries. Moreover, we assume that all countries start more or less at the same level, as the development of autonomous HDV lies in the far future (2040 and behind). The knowledge transfer among EU member states should be higher for future innovations than in early decades for conventional traffic technologies. Table C.20 shows the job keys of the service “automated heavy-duty vehicles”.

Table C.20 job keys for heavy-duty vehicles (automated)

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
				Status quo				
Progressive	25%	20%	4%	4%	7%	19%	20%	**100%**
Average	25%	20%	4%	4%	7%	19%	20%	**100%**
Lagging	25%	20%	4%	4%	7%	19%	20%	**100%**
				2025				
Progressive	20%	21%	5%	9%	9%	18%	18%	**100%**
Average	20%	21%	5%	9%	9%	18%	18%	**100%**
Lagging	20%	21%	5%	9%	9%	18%	18%	**100%**
				2040				
Progressive	5%	21%	6%	25%	11%	14%	18%	**100%**
Average	5%	21%	6%	25%	11%	14%	18%	**100%**
Lagging	5%	21%	6%	25%	11%	14%	18%	**100%**
				2050				
Progressive	1%	19%	6%	37%	11%	11%	15%	**100%**
Average	1%	19%	6%	37%	11%	11%	15%	**100%**
Lagging	1%	19%	6%	37%	11%	11%	15%	**100%**

Source: M-Five.

Train

Although rail transport is not in the focus of this study, we calculated job keys for train services as well. The reasons for that are potential indirect effects if CAD makes train services more attractive (because of closing the so-called “last mile” between train stations and destinations for instance). The job keys for train services mainly based on two statistics, which were published by Austrian Federal Railways (ÖBB) and the Association of public transport companies in France (UTP). As these statistics include also non-rail services like buses and non-passenger services like rail freight transport, we made several adjustments (less drivers and more stewards for instance). For the future, we assume an increasing number of IT jobs and a moderate reduction of driver and maintenance jobs because of higher automation and connectivity in the field of train technologies. Table C.21 shows the job keys for the service “train”.

Table C.21 job keys for trains

CAD Profile	Driver	Admin.	Mgmt.	IT	Cust. Serv.	Stew./ Operat.	Maint.	TOTAL
				Status quo				
Progressive	55%	6%	2%	8%	4%	10%	15%	100%
Average	55%	6%	2%	7%	4%	10%	16%	100%
Lagging	55%	6%	2%	6%	4%	10%	17%	100%
				2025				
Progressive	55%	6%	2%	9%	4%	9%	15%	100%
Average	55%	6%	2%	8%	4%	9%	16%	100%
Lagging	55%	6%	2%	7%	4%	9%	17%	100%
				2040				
Progressive	50%	6%	2%	20%	4%	7%	11%	100%
Average	55%	6%	2%	13%	4%	8%	12%	100%
Lagging	55%	6%	2%	10%	4%	9%	14%	100%
				2050				
Progressive	45%	6%	2%	30%	4%	6%	7%	100%
Average	50%	6%	2%	22%	4%	7%	9%	100%
Lagging	55%	6%	2%	15%	4%	8%	10%	100%

Source: M-Five.

Overview of job key sources

Table C.22 shows the different sources and methods which were used to generate the job keys. In the best case, the splits could directly be taken from literature. As for many countries we had no such sources, we used the job splits according to the generic keys mentioned above (see Table C.8).

Table C.22 Sources of job keys per service (overview)

COUNTRY	BUS classic	BUS auto.	TAXI classic	TAXI auto.	Carsharing	Ridesharing	HDV classis	HDV auto.	LDV classic	LDV auto.	Train
AT	☑	☑	☑☑	☑	☑	☑	☑	☑	☑	☑	☑☑
BE	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
BG	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
CH	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
CY	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☒
CZ	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
DE	☑☑	☑☑	☑☑	☑	☑☑	☑☑	☑☑	☑	☑☑	☑	☑
DK	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
EE	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
EL	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
ES	☑☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
FI	☑	☑	☑☑	☑	☑	☑	☑	☑	☑	☑	☑
FR	☑☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑☑
HR	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
HU	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
IE	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
IT	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
LT	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑

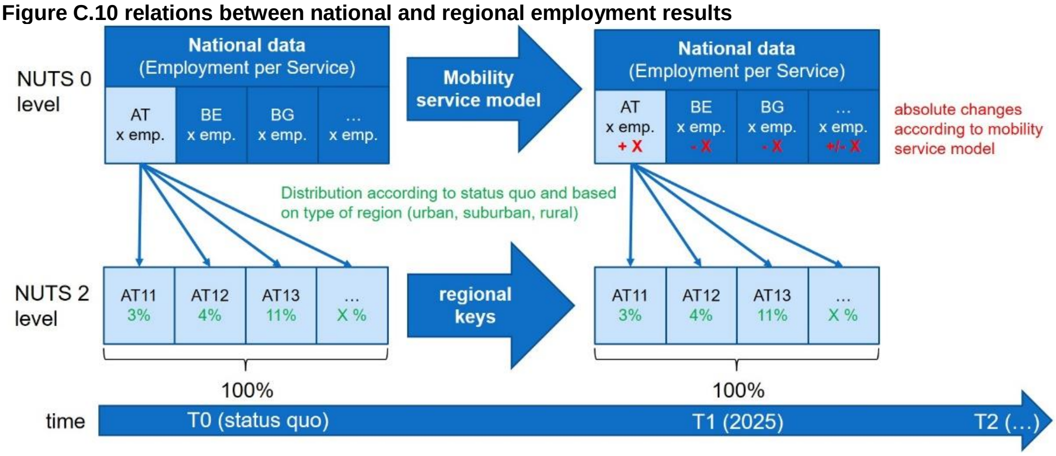
COUNTRY	BUS classic	BUS auto.	TAXI classic	TAXI auto.	Carsharing	Ridesharing	HDV classis	HDV auto.	LDV classic	LDV auto.	Train
LU	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
LV	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
MT	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☒
NL	☑	☑	☑☑	☑	☑	☑	☑	☑	☑	☑	☑
NO	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
PL	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
PT	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
RO	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
SE	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
SI	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
SK	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
☐☐	job key based directly on literature / stakeholders										
☐	job key based mainly on own assumptions (generic approach)										
☐	Job key not required (service not available)										

Source: M-Five.

Approach of regional keys (spatial breakdown)

The development of the regional keys was carried out to build a disaggregated framework for the distribution of national-based job numbers on different regions (NUTS II zones) per country. Figure C.10 shows the general relations between the results on national level and on regional level: the mobility services model generates the numbers of employees on national level (NUTS 0) per service and per country. The results are absolute numbers which change over time. The regional keys are the relative split (percentages) for the distributions of national results on regional level. This distribution depends on the share of status quo employment and on the type of region according to the demographic density. The specific method for the different services is explained below.

Figure C.10 relations between national and regional employment results



Source: M-Five.

Bus (classic, SAE Level 1-4)

To calculate the regional keys for conventional bus, we collected the current public transport jobs per NUTS 2 zone. By dividing by the population per NUTS 2 zones, we got the number of public transport employees per 1,000 inhabitants for regions with available real-life data. To vary this average depending on regional type, the regions where classified in three subtypes (urban, suburban, and rural) dependent on the population density. When there was no real data for a specific NUTS 2 zone, we took the average employees per 1,000 inhabitants according to its regional type (urban, suburban, and rural). For example, if the region type is for example “urban”, we took the average of the filled urban zones with real data and multiplied it with the inhabitants (in thousands) of the NUTS 2 zone in question.

Another calculation was necessary to eliminate the railway jobs, which are sometime included in the job data. For this purpose, we investigated the existence (or non-existence) of near distance trains in the different NUTS zones. If no train or tram systems exist in a region (meaning that all jobs in local traffic are bus jobs) we used the total numbers. If there are tram and/or train jobs in a region, we assumed a share of 25% rail jobs, based on data from the German Public Transport association VDV.

To make sure that the percentages of bus employment fits the real proportions, we used the following quality measures:

- Real data on NUTS II level as far as possible: own research findings and data provided by UITP, balancing factor for completion;
- Differentiation of employees per 1,000 inhabitants according to region category (urban, suburban, and rural) to avoid disadvantages caused by spatial imbalance (e.g. public transport employment in urban regions above average);
- Reduction in regions with trains and/or trams based on regional categorisation in terms of existing/non-existing public transport systems.

Robo-Bus (automated, SAE level 5)

Due the lack of data for future transport services, the same regional keys as for conventional buses (see above) were also taken for robo-buses.

Taxi (classic, SAE Level 1-4)

To build the regional key for conventional taxis, we took the number of taxi employees per country (Frazzani et al., 2016)[35]. By dividing with the population per NUTS 0 zone (national level) we obtained the number of taxi employees per 1,000 inhabitants for every country. We used this average to split the NUTS 2 numbers according to the population per region. The next step was the variation of this average depending on regional type (urban, suburban, and rural according to the population density). The variation per region was not necessary when the sum was equal (or nearby) the NUTS 0 employment for the specific country. If we have vehicle numbers for a NUTS 2 zone (taxi cars per country) we calculated in such a way, that the number of jobs fits the number of taxi cars, according to the ratio of similar research projects. In few cases, we have real job numbers on NUTS II level. Then we took this share directly.

To make sure that the percentages of taxi employment fits the real proportions we used the following quality measures:

- National job numbers based mainly on real data (report on behalf of the EU by Frazzani et al. 2016);
- The regional splits were calculated country by country to check national specifications;
- Local fleet data on city level (provided by UITP) was used to check the relations between the number of taxis (vehicles) and jobs in taxi operations in the particular region;
- The factor of employment per taxi was validated with a former project in the German market (we made some minor changes according to specifications in other countries).

[35] Frazzani, Simona; Grea, Gabriele, Zamboni, Alessandro (2016): Study on passenger transport by taxi, hire car with driver and ridesharing in the EU – Final Report. Online: https://ec.europa.eu/transport/sites/transport/files/2016-09-26-pax-transport-taxi-hirecar-w-driver-ridesharing-final-report.pdf.

Robo-Taxi (automated, SAE level 5)

Due the lack of data for future transport services, the same regional keys as for conventional taxis (see above) were taken for robo-taxis.

Car sharing

The regional keys for car sharing are based on car sharing vehicle numbers for German NUTS II zones. The source is the German car sharing association (*Bundesverband CarSharing*, bcs) which has data for the fleets per town. We built clusters for cities within the same NUTS II zone and added the particular vehicle numbers. Then we calculated the average of car sharing vehicles per 1,000 inhabitants per NUTS II zone. This served as the basis to build generic averages for three kinds of regions: urban, suburban, and rural (depending on the population density). Then we made country specific variations of these generic averages and finally got the total sum of nearly 62.000 car sharing vehicles in Europe (this sum was known from two external sources, namely Shaheen/Cohen, 2020 and Erich 2018)[36]. Finally, an employment key of former projects was used to get the car sharing employees per NUTS 2 zone (0.15 employees per car sharing vehicle).

To make sure that the percentages of car sharing employment fits the real proportions we used the following quality measures:

- the average densities of car sharing vehicles per 1,000 inhabitants based on the real data of Germany (assumption that Germany is the lead market of car sharing in Europe);
- the factor of employment per car sharing vehicle was validated in a former research project in the German market (we made some minor changes according to specifications in other countries);
- the total numbers of car sharing vehicles in Europe is known and based on two different sources;
- we varied the car sharing vehicles per 1,000 inhabitants according to region category (urban, suburban, and rural) to avoid disadvantages caused by spatial imbalance (more car sharing vehicles in urban than in suburban and rural regions).

Ridesharing

Due to the lack of data for this service, we combined two other keys: until 2025 (short-term) we took the same regional key as for car sharing. Reasons are the characteristics, which are currently similar to car sharing as this service is mainly located in bigger cities and operates with small vehicles (mostly cars or vans). We assume that these characteristics will be the same in the next years as today. For mid-term development, we assume a transition towards bus services as ridesharing could become a flexible form (Mobility on Demand) of public transport. Therefore, we took the regional keys of car sharing for the next years and the regional key for (robo-)bus for the years after 2040. The intermediate development was filled with continuous intermediate values.

Light-duty vehicles (classic, SAE Level 1-3)

To create the regional keys for conventional light-duty vehicles, we took the spatial distribution of post and postal & courier services. M-Five obtained these employment numbers directly form EUROSTAT (NACE Code H53) on NUTS II level – provided by IRU.

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[36] Shaheen, Susan; Cohen, Adam (2020): Innovative Mobility: Carsharing Outlook – spring 2020; Carsharing Market Overview, Analysis, and Trends. University of California, Berkeley. Available on https://escholarship.org/uc/item/61q03282
Erich, Max (2018): Car sharing unlocked – How to get to a 7.5 million shared car fleet in Europe by 2035. ING Economics Department. Available on https://think.ing.com/uploads/reports/ING_-_Car_sharing_unlocked.

Light-duty vehicles (automated, SAE Level 4 & 5)

Due to the lack of data for future transport services, the same regional keys as for conventional light-duty vehicles (see above) were also taken for automated LDV.

Heavy-duty vehicles (classic, SAE Level 1-3)

The calculation of the regional keys in the HDV sector is based on employment numbers from EUROSTAT of the NACE sector “freight transport by road” (H49.4.1) and partly “removal services” (H49.4.2). Since this data was almost only available at NUTS1 level, the NUTS2 values were derived from these. The employees are distributed proportionally to the population density among the NUTS II zones.

To make sure that the percentages of HDV employment fits the real proportions, we used the following quality measures:

- All data for NUTS1 level is original data from EUROSTAT;
- The distribution among the NUTS2 zones was made according to employees per 1,000 inhabitants of the correspondent NUTS1 zones. Only in few cases, there was a lack of numbers in terms of NUTS1 level. Then we took the average of neighbour zones and made some adjustments to get the national total result.

Heavy-duty vehicles (automated, SAE Level 4 & 5)

Due to the lack of data for future transport services, the same regional keys as for conventional light-duty vehicles (see above) were also taken for automated HDV.

Table C.23 includes the different sources and processes which the M-Five team used to create the region keys for the different transport services. For a simple overview, only the MS level is shown.

Table C.23 sources and processes of the creation of regional keys

COUNTRY	BUS classic	BUS auto.	TAXI classic	TAXI auto.	Carsharing	Ridesharing	HDV classis	HDV auto.	LDV classic	LDV auto.
AT	☑☑	⇆	☑☑☑☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑☑	⇆
BE	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑	⇆
BG	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑	⇆
CH	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	⇆	⇆
CY	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
CZ	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑	⇆
DE	☑☑☑☑	⇆	☑☑☑	⇆	☑☑	⇆	☑☑☑	⇆	☑☑☑☑	⇆
DK	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑	⇆
EE	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
EL	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑☑	⇆
ES	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑	⇆
FI	☑☑	⇆	☑	⇆	☑	⇆	☑☑	⇆	☑☑	⇆
FR	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑	⇆
HR	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑☑	⇆
HU	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑	⇆
IE	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑	⇆
IT	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑	⇆
LT	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑	⇆
LU	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒

COUNTRY	BUS classic	BUS auto.	TAXI classic	TAXI auto.	Carsharing	Ridesharing	HDV classis	HDV auto.	LDV classic	LDV auto.
LV	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
MT	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
NL	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑	⇆
NO	☑☑☑☑	⇆	☑☑☑☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑☑	⇆
PL	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑	⇆
PT	☑☑	⇆	☑	⇆	☑	⇆	☑☑	⇆	☑	⇆
RO	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑☑	⇆	☑☑☑☑	⇆
SE	☑☑	⇆	☑☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑	⇆
SI	☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	⇆	⇆
SK	☑☑	⇆	☑	⇆	☑	⇆	☑☑☑	⇆	☑☑☑☑	⇆

☑☑☑☑	Percentages of total employees based completely on real data on NUTS II level
☑☑☑	% of total employees calculated completely with real national data[37]
☑☑	% of total employees calculated partly with real data on NUTS II level and with other source
☑	Percentages of total employees calculated mainly with auxiliary data from other sources
⇆	no percentages because of too less real data (keys from similar services were used)
☒	no regional key necessary as no more than one NUTS II zone exist in this country

Source: M-Five.

Detailed modelling results on employment impacts in ASTRA

Here, we show detailed results of the ASTRA model, which are not part of the main chapters of this report but still relevant for the different models.

Sectoral employment effects

The tables below present the results for absolute sectoral employment in persons, the percentage change of employment against the baseline as well as against the base year 2020 for EU27.

Table C.24 Sectoral employment of EU27 in relevant sectors, Baseline (ASTRA)

Baseline	Sectoral Employment in Persons				% Change to 2020		
Sector	2020	2025	2035	2050	2025	2035	2050
Vehicles	4,362,489	4,339,444	4,258,887	4,206,752	-0.53%	-2.37%	-3.57%
Electronics	1,823,671	1,825,548	1,833,449	1,850,586	0.10%	0.54%	1.48%
Computers	283,393	277,377	268,110	259,169	-2.12%	-5.39%	-8.55%
Communication	2,720,278	2,699,200	2,658,583	2,622,539	-0.77%	-2.27%	-3.59%
Construction	14,161,338	14,035,654	13,768,165	13,413,011	-0.89%	-2.78%	-5.28%

Source: M-Five.

Table C.25 Sectoral employment of EU27 in relevant sectors, Scenario 1 (ASTRA)

Scenario 1	Sectoral Employment in Persons				% Change to 2020			% Change to Baseline		
Sector	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
Vehicles	4,362,470	4,338,684	4,258,845	4,247,059	-0.55%	-2.38%	-2.65%	-0.02%	0.00%	0.96%
Electronics	1,824,612	1,831,418	1,836,077	1,883,442	0.37%	0.63%	3.22%	0.32%	0.14%	1.78%
Computers	283,394	277,515	268,854	262,174	-2.07%	-5.13%	-7.49%	0.05%	0.28%	1.16%

[37] partly on higher level (NUTS 0 or 1).

Communication	2,720,366	2,700,141	2,662,713	2,629,836	-0.74%	-2.12%	-3.33%	0.03%	0.16%	0.28%
Construction	14,162,688	14,044,876	13,768,557	13,497,944	-0.83%	-2.78%	-4.69%	0.07%	0.00%	0.63%

Source: M-Five.

Table C.26 Sectoral employment of EU27 in relevant sectors, Scenario 2 (ASTRA)

Scenario 2	Sectoral Employment in Persons				% Change to 2020			% Change to Baseline		
Sector	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
Vehicles	4,362,469	4,338,793	4,259,378	4,242,547	-0.54%	-2.36%	-2.75%	-0.02%	0.01%	0.85%
Electronics	1,824,610	1,832,313	1,835,769	1,877,966	0.42%	0.61%	2.92%	0.37%	0.13%	1.48%
Computers	283,395	277,644	268,988	261,408	-2.03%	-5.08%	-7.76%	0.10%	0.33%	0.86%
Communication	2,720,335	2,700,530	2,662,975	2,612,492	-0.73%	-2.11%	-3.96%	0.05%	0.17%	-0.38%
Construction	14,162,600	14,046,200	13,770,012	13,470,297	-0.82%	-2.77%	-4.89%	0.08%	0.01%	0.43%

Source: M-Five.

Table C.27 Sectoral employment of EU27 in relevant sectors, Scenario 3 (ASTRA)

Scenario 3	Sectoral Employment in Persons				% Change to 2020			% Change to Baseline		
Sector	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
Vehicles	4,362,464	4,340,421	4,258,497	4,216,052	-0.51%	-2.38%	-3.36%	0.02%	-0.01%	0.22%
Electronics	1,823,657	1,826,766	1,839,169	1,858,920	0.17%	0.85%	1.93%	0.07%	0.31%	0.45%
Computers	283,393	277,458	268,530	258,864	-2.09%	-5.24%	-8.66%	0.03%	0.16%	-0.12%
Communication	2,720,264	2,700,243	2,661,438	2,616,907	-0.74%	-2.16%	-3.80%	0.04%	0.11%	-0.21%
Construction	14,161,428	14,040,652	13,781,791	13,402,166	-0.85%	-2.68%	-5.36%	0.04%	0.10%	-0.08%

Source: M-Five.

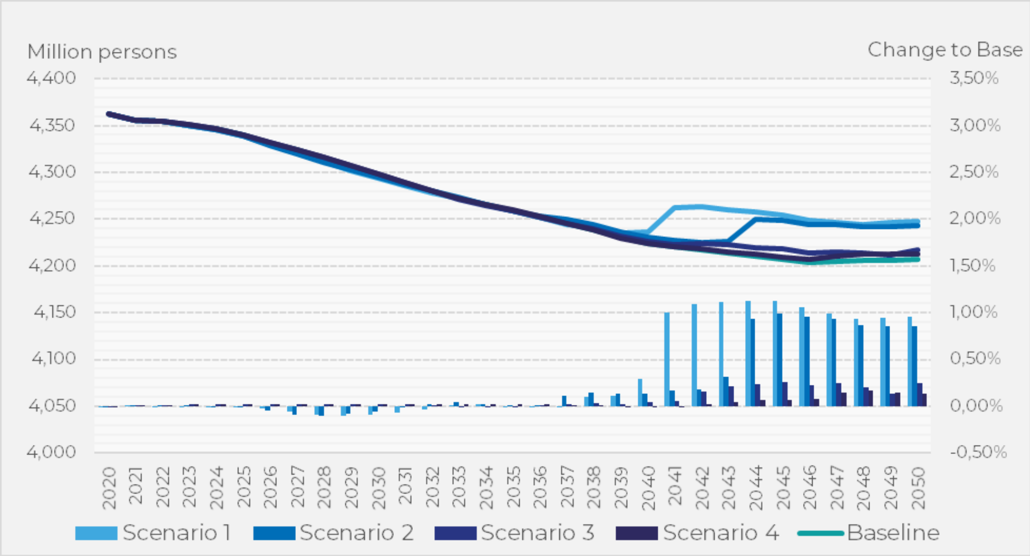
Table C.28 Sectoral employment of EU27 in relevant sectors, Scenario 4 (ASTRA)

Scenario 4	Sectoral Employment in Persons				% Change to 2020			% Change to Baseline		
Sector	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
Vehicles	4,362,463	4,340,435	4,259,772	4,212,297	-0.50%	-2.35%	-3.44%	0.02%	0.02%	0.13%
Electronics	1,823,656	1,825,996	1,837,501	1,849,108	0.13%	0.76%	1.40%	0.02%	0.22%	-0.08%
Computers	283,394	277,457	268,275	258,944	-2.10%	-5.34%	-8.63%	0.03%	0.06%	-0.09%
Communication	2,720,254	2,700,146	2,660,781	2,613,468	-0.74%	-2.19%	-3.93%	0.04%	0.08%	-0.35%
Construction	14,161,237	14,038,985	13,779,098	13,412,461	-0.86%	-2.70%	-5.29%	0.02%	0.08%	0.00%

Source: M-Five.

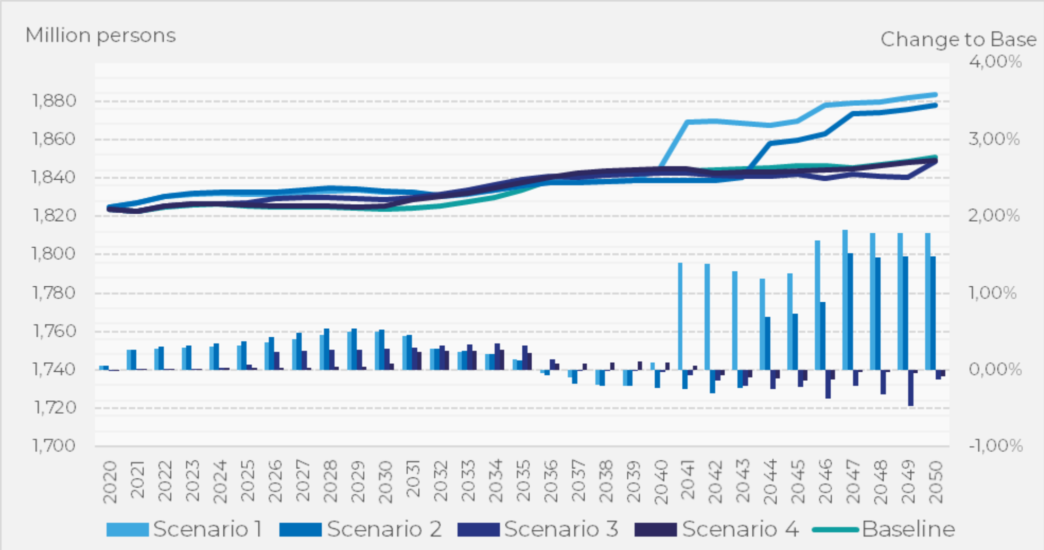
The following figures present the time profile of sectoral employment from 2020 until 2050 for the major sectors affected by CAD.

Figure C.11 Sectoral employment of EU27 in the vehicle sector, all scenarios (ASTRA)



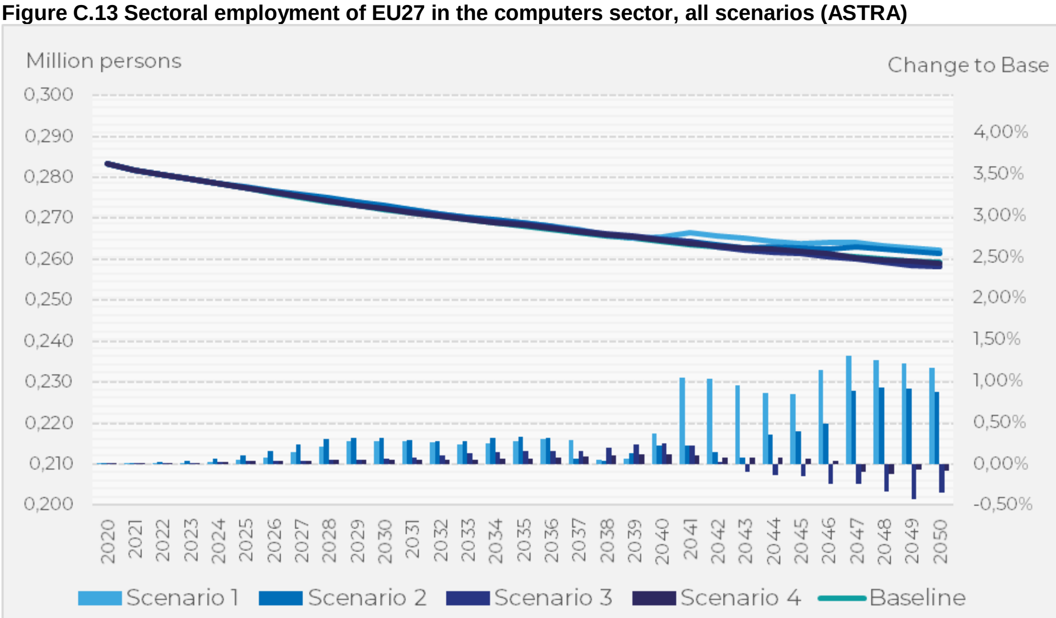
Source: M-Five.

Figure C.12 Sectoral employment of EU27 in the electronics sector, all scenarios (ASTRA)



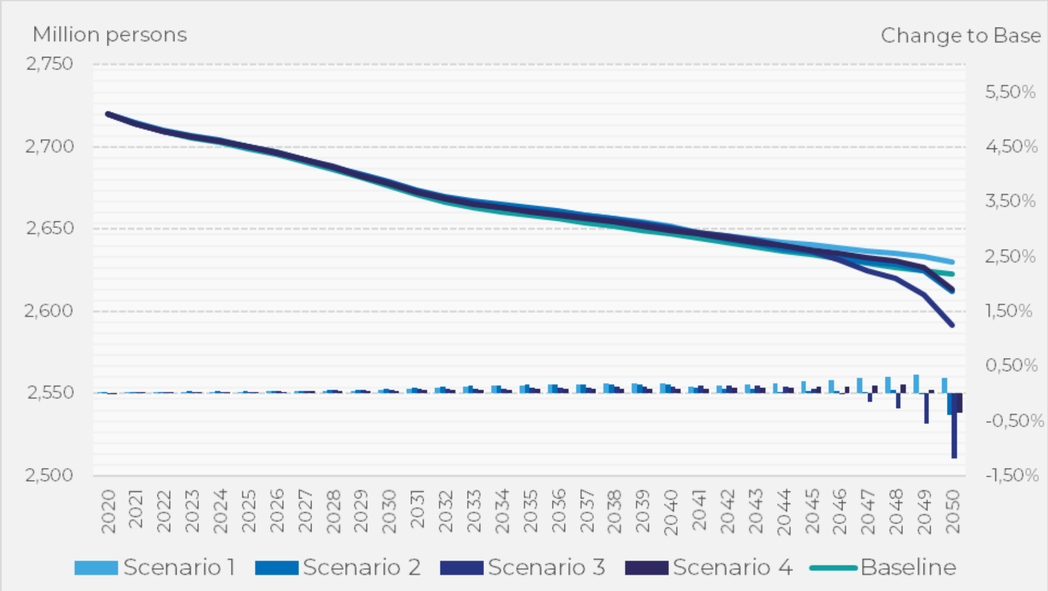
Source: M-Five.

Figure C.13 Sectoral employment of EU27 in the computers sector, all scenarios (ASTRA)



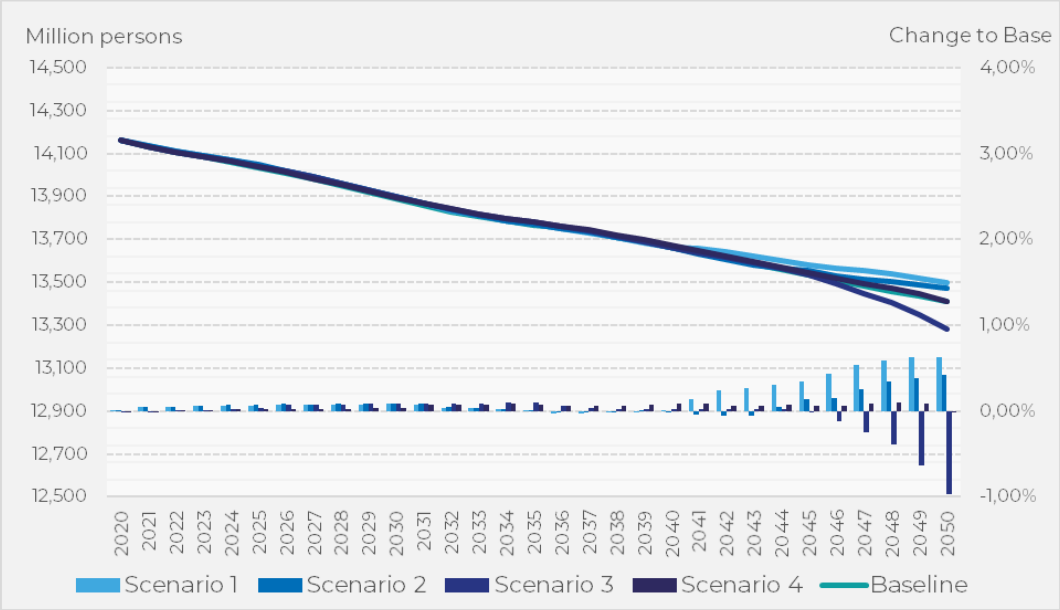
Source: M-Five.

Figure C.14 Sectoral employment of EU27 in the communication sector, all scenarios (ASTRA)



Source: M-Five.

Figure C.15 Sectoral employment of EU27 in the construction sector, all scenarios (ASTRA)



Source: M-Five.

Regional distribution of manufacturing

The following sub-sections show selected clusters regions with high potential for CAD manufacturing. For each region, it should be taken into account that not only the largest city but also large parts of the surrounding areas – including neighbouring cities – are included.

FR10 – Île-de-France (France)

The main headquarters location in this region is Paris. Nearly 700,000 employees work for CAD-relevant companies with headquarters based in this NUTS zone. Important automotive players are the OEMs *PSA* and *Renault* as well as *Valeo*. This supplier has totally more than 100,000 employees and holds nearly 300 CAD patents. There is also the public transport provider *Transdev* which has much activities in the context of CAD. A test site (“Autonomous Lab”) is located in Paris-

Saclay (Renault 2019)[38]. Table C.29 shows a selection of CAD-related companies in the region of Paris (Île-de-France) in France.

Table C.29 CAD-related companies in the NUTS zone *Île-de-France* (selection[39])

Segment	Company	Brand	HQ Location	Employees (overall[40])
OEM	PSA	Citroen	Paris	211,000
OEM	PSA	Peugeot	Paris	
OEM	PSA	DS	Paris	
OEM	Renault	Renault	Paris	183,000
Supplier	Valeo	Valeo	Paris	113,600
Engineering Service Provider (ESP)	Altran Technologies S.A.	-	Paris	47,000
ESP	Alten Group	-	Paris	33,700
ESP	Expleo Group SAS	-	Montigny-le-Bretonneux	15,000
Public Transport Provider	Transdev Group	-	Issy-les-Moulineaux	74,300
				677,600

Source: CAM (Automotive Database), Automobilwoche 2019[41], own research by M-Five.

DE21 – Oberbayern (Germany)

The region of Upper Bavaria is known as the "Isar Valley" (referring to Silicon Valley), because of its Software-Companies as well as its potentials in the fields of microelectronics and in general high technology. The main headquarters locations in this region is Munich and Ingolstadt. Munich houses the *BMW* headquarter while *Audi* (a sub-company of *VW*) is located in Ingolstadt which is situated in the northern part of this NUTS zone. As Table C.30 shows that there are also several start-ups and engineering service providers located in Munich or nearby. The central supplier Continental is represented by a subsidiary in Ingolstadt. Totally more than 500,000 employees work for CAD-relevant companies with headquarters based in this NUTS zone. The area is connected to the Highway test site *A9 Digital Motorway Testbed* from Nuremberg via Ingolstadt to Munich. Together with the IT company *door2door*, Munich's public transport operators offer the *IsarTiger* on-demand service. In terms of the density of free-floating[42] car sharing vehicles per 1,000 inhabitants, Munich ranks first among German cities.[43] Table C.30 shows a selection of CAD-related companies in the region of Munich (*Oberbayern*, Upper Bavaria) in Germany.

38 Renault (2019): Paris-Saclay Autonomous Lab – new autonomous, electric and shared mobility services. Online: https://media.group.renault.com/global/en-gb/groupe-renault/media/pressreleases/21225791/paris-saclay-autonomous-lab-de-nouveaux-services-de-mobilite-autonome-electrique-et-partagee (last access on 10th January 2020).

39 In the area of the NUTS zones are quite many more CAD-related companies. The table gives only a first impression of big companies and some SMEs. The research is ongoing.

40 The numbers of employees includes many persons with works at other locations then the headquarters. The employment in the NUTS zone are significantly small especially in case of the OEMs. For this reason, we start to collect numbers of employees in sub-sectors within the NUTS zones, like employment in ADAS located in the regions.

41 Automobilwoche (Ed.) (2019): *Die weltweit 25 umsatzstärksten Entwicklungsdienstleister 2018*. Online: https://www.automobilwoche-datencenter.de (logged-in users only).

42 Without fixed stations (one-way-using is possible in defined areas).

43 bcs (2019: CarSharing Städteranking 2019. Bundesverband CarSharing, online: https://carsharing.de/alles-ueber-carsharing/carsharing-zahlen/carsharing-staedteranking-2019 (last access at 15. January 2020).

Table C.30 CAD-related companies in the NUTS zone Oberbayern (selection)

Segment	Company	Brand	HQ Location	Employees (overall)
OEM	BMW AG	BMW	Munich	134,682
OEM	BMW AG	Mini	Munich	-
OEM	Volkswagen AG	Audi	Ingolstadt	91,247
OEM	Volkswagen AG	TRATON	Munich	81,000
OEM	Siemens Mobility GmbH	e.g. VAL	Munich	ca. 30,000
Start-up	ARGO AI / AUDI	AID	Munich	-
Start-up		Apex AI	Munich	-
Start-up	holoride GmbH	-	Munich	-
Supplier	Bourns Sensors GmbH	-	Taufkirchen	-
Supplier	Conti Temic microelectronic GmbH	-	Ingolstadt	1,611
Consulting	NTT Data Deutschland GmbH	-	Munich	-
ESP	Altran Deutschland S.A.S. & Co. KG	-	Munich	-
ESP	ESG Elektronik-system- und Logistik-GmbH	-	Munich	2,000
ESP	In-tech GmbH	-	Garching	1,500
ESP	ASAP	-	Gaimersheim	1,150
ESP	FDTech GmbH	-	Chemnitz/Munich	ca. 80
ESP	Intenta GmbH	-	Chemnitz branch Ingolstadt	160
				> 550,00

Source: CAM (Automotive Database), M-Five (RE-MOB Database), automotiveIT 2020[44], Automobilwoche 2019, own research by M-Five.

DE11 – Stuttgart (Germany)

The main headquarters location in this region is Stuttgart. A total of more than 700,000 employees work for CAD-relevant companies based in this NUTS zone. As seen above this region is outstanding in the mobility industries in general as well as for CAD in particular. The company Bosch is one of the most important suppliers worldwide and also a leader in CAD components. Additionally, the OEMs *Daimler* and *Porsche* (part of the VW group) are based in this NUTS zone. Together with *Daimler's* subsidiary *Moovel*, Stuttgart's public transport operators offer the *SSB flex* on-demand service. The region is connected to the test site "Test Area Autonomous Driving Baden-Wuerttemberg" which also includes the city of Heilbronn in the northern part of the NUTS zone. Table C.31 shows a selection of CAD-related companies in the region of Stuttgart in Dresden.

[44] AutomotiveIT (Ed.) (2020): *IT for automotive – Marktuebersicht*. Media-Manukatur, Pattensen.

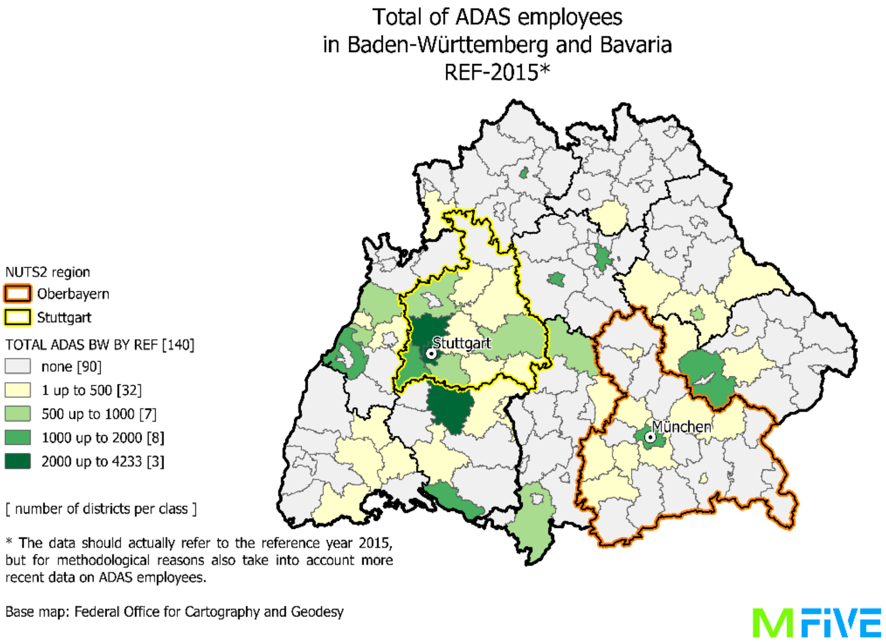
Table C.31 CAD-related companies in the NUTS zone Stuttgart (selection)

Segment	Company	Brand	HQ Location	Employees (overall)
OEM	Daimler AG	Mercedes-Benz	Stuttgart	145,436
OEM	Daimler AG	Smart	Stuttgart	-
OEM	Daimler AG	Mercedes-Benz Trucks	Stuttgart	82,953
OEM	Daimler AG	Mercedes- Benz Vans	Stuttgart	26,210
OEM	Daimler AG	Mercedes-Benz Bus	Stuttgart	18,770
OEM	Volkswagen AG	Porsche	Stuttgart	32,020
Supplier	Robert Bosch GmbH	Bosch	Stuttgart	409,900
Supplier	Eberspächer	-	Esslingen a. N.	890
Supplier	Hirschmann Car Communication GmbH		Neckartenzlingen	375
Supplier	TE Connectivity	-	Woert	1,543
Supplier	Valeo Schalter + Sensoren GmbH	-	Bietigheim-Bissingen	1,199
Consulting/ Analytics	DXC Technology Deutschland	-	Böblingen	-
ESP	Bertrandt	-	Ehningen	12,000
				> 715,000

Source: CAM (Automotive Database), M-Five (RE-MOB Database), automotiveIT 2020, Automobilwoche 2019, own research by M-Five.

Regarding specific CAD professions we started to quantify employment in the field of ADAS (initially in Germany). Further professions will be investigated for all selected cluster. The map below (Figure C.16) shows the NUTS 2 zones "Stuttgart" and "Oberbayern" together with the absolute number of employees in the field of Advanced Driver Assistance Systems (ADAS). The classification on the map shows also the level of NUTS 3 zones. This also highlights the differences *within* the NUTS 2 zones. The colours show that the immediate areas of the cities of Stuttgart and Munich are relevant for ADAS employment. This is partly due to the fact that the headquarters of large companies are located in the cities of Munich and Stuttgart with highly qualified employees.

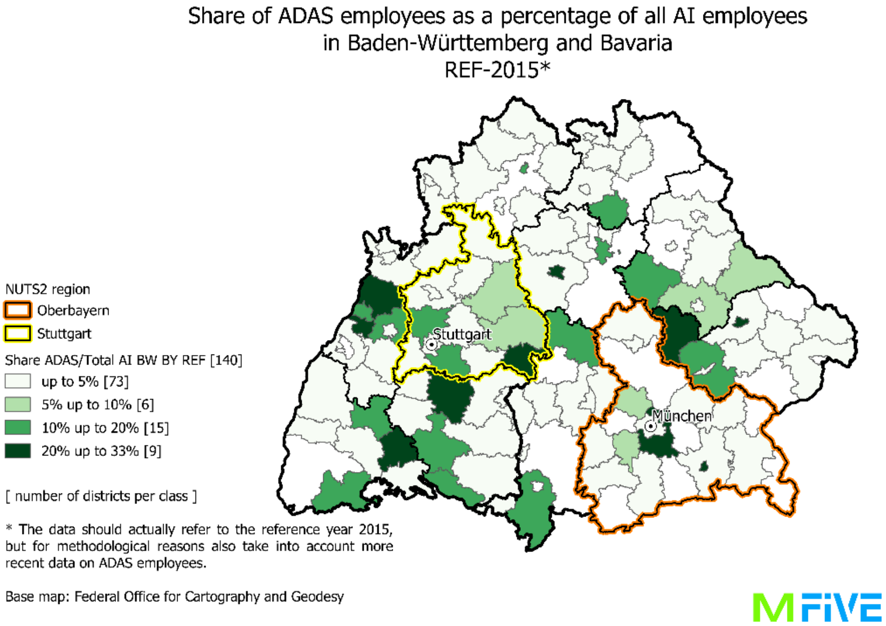
Figure C.16 Total ADAS-related employees in the NUTS 2 zones *Stuttgart* and *Oberbayern*



Source: M-Five.

It is important to note, that every NUTS 3 zone (smaller then NUTS 2) in the German federal states of Bavaria and Baden-Württemberg includes people working in the sector of automotive industry. In a further step, we have therefore investigated the share of ADAS employees in all employees in the automotive industry sector. The map in Figure C.17 shows that the relative proportions of CAD-relevant employees also reach peak values in the direct neighbourhood of the NUTS 2 zones *Stuttgart* and *Oberbayern*. This could be an indication that neighbouring regions at NUTS 2 level may also be regarded as part of the CAD clusters.

Figure C.17 Share of ADAS-related employees of Employees of the automotive industry in the NUTS 2 zones *Stuttgart* and *Oberbayern*



Source: M-Five.

DED 2 – Dresden (Germany)

The NUTS zone Dresden in Germany is a centre of the so called "Silicon Saxony", a registered industry association of nearly 300 companies in the microelectronics and related sectors with around 40,000 employees. The main companies' location in this region is Dresden. For example, the US semiconductor producer *GlobalFoundries* has a plant in the capital of Saxony. A test site for connected and automated driving is located at the airport Dresden and at some other places in the city. Table C.32 shows a selection of CAD-related companies in the region of Dresden in Germany.

Table C.32 CAD-related companies in the NUTS zone Dresden (selection)

Segment	Company	Brand	HQ Location	Employees (overall)
Supplier	*GlobalFoundries*	-	Santa Clara (USA)	16,000
Supplier	joynext	-	Dresden	1,200

Source: CAM (Automotive Database), M-Five (RE-MOB Database), automotiveIT 2020, Automobilwoche 2019, own research by M-Five.

DED 4 – Chemnitz (Germany)

The NUTS zone Chemnitz in Germany also belongs to the "Silicon Saxony" and hosted the network *CADA – Chemnitz automated driving alliance*. The main headquarters location in this region is Chemnitz. The Chemnitz University of Technology created the CAD-related start-up *NAVENTIK*. Table C.33 shows a selection of CAD-related companies in the region of Chemnitz in Germany.

Table C.33 CAD-related companies in the NUTS zone Chemnitz (selection)

Segment	Company	Brand	HQ Location	Employees (overall)
Start-up	NAVENTIK	-	Chemnitz	-
Supplier	noritel	-	Hardmannsdorf	-
Supplier	FusionSystems	-	Chemnitz	-

Source: CAM (Automotive Database) and own research by M-Five.

NL41 – Noord-Brabant (Netherlands)

The NUTS zone Noord-Brabant in the Netherlands is the fastest growing region in the Netherlands. The electric car manufacturer *Tesla* operates an assembly plant in Tilburg. A truck plant of *DAF* is located in Eindhoven. The company *NXP Semiconductor*s is a global semiconductor manufacturer headquartered in Eindhoven too. According to its own statements *NXP* is the world's largest chip supplier for the automotive industry and market leader in Europe. Even smaller CAD-related semiconductors manufactures like the German company *Dream Chip Technologies* have locations in Noord-Brabant.

Despite the selection mentioned above we will take these additional regions still into account. Especially, if further investigations show gaps of CAD development relevant aspects in the selected regions, it is possible to choose one of these regions for an additional perspective. Table C.34 shows a selection of CAD-related companies in the region of Noord-Bradant in the Netherlands.

Table C.34 CAD-related companies in the NUTS zone Noord-Brabant (selection)

Segment	Company	Brand	HQ Location	Employees (overall)
OEM	DAF	-	Eindhoven	9,400 (DAF Trucks N.V.)
Supplier	NXP Semiconductors	-	Eindhoven	31,000
Supplier	Dream Chip Technologies	-	Garbsen (DE)	-

Source: CAM (Automotive Database) and own research by M-Five.

SE11 – Stockholm (Sweden)

The Swedish capital Stockholm is the headquarters of Autoliv, a company offering safety technology for vehicles. There are also several start-ups in the city with a focus on connected and automated driving. Table C.35 shows a selection of CAD-related companies in the region of Stockholm in Sweden.

Table C.35 CAD-related companies in the NUTS zone Stockholm (selection)

Segment	Company	Brand	HQ Location	Employees (overall)
Supplier	Autoliv	Autoliv	Stockholm	67,000
Consulting/ Analytics	4dialog	-	Stockholm	-
Consulting/ Analytics	einride.tech	-	Stockholm	-

Source: CAM (Automotive Database) and own research by M-Five.

SE23 – Västsverige (Sweden)

The NUTS zone Västsverige in the south-western part of Sweden includes the city of Gothenburg. The city is a central location for the Volvo and Polestar brands which are both owned by the Chinese manufacturer Geely. Nearby of this city lays the test site *Active Safety Test Area Zero* (AstaZero), beside the *Hällered Proving Ground*, which is the test site of the Volvo. Table C.36 shows a selection of CAD-related companies in the region of Västsverige in Sweden.

Table C.36 CAD-related companies in the NUTS zone Västsverige (selection)

Segment	Company	Brand	HQ Location	Employees (overall)
OEM	Geely	Volvo	Gothenburg	104,000
OEM	Geely	Polestar	Gothenburg	110
Start-up	Volvo	Zenuity	Gothenburg	600

Source: CAM (Automotive Database) and own research by M-Five.

Impact of CAD on GDP

The tables below present the results for absolute GDP of the EU27 aggregate as well as on country level in Mio €2005, the percentage change against the baseline as well as against the base year 2020.

Table C.37 Development of GDP of EU27, all scenarios (ASTRA)

	GDP EU27 in Mio €2005				% Change to 2020			% Change to Baseline		
Scenario	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
Baseline	12,129,181	12,987,367	14,942,739	18,468,934	7.08%	23.20%	52.27%	0.00%	0.00%	0.00%
Scenario 1	12,130,014	13,002,049	14,981,016	18,666,868	7.19%	23.50%	53.89%	0.11%	0.26%	1.07%
Scenario 2	12,131,440	13,004,983	14,983,175	18,548,876	7.20%	23.51%	52.90%	0.14%	0.27%	0.43%
Scenario 3	12,127,227	12,991,259	14,975,831	18,560,558	7.12%	23.49%	53.05%	0.03%	0.22%	0.50%
Scenario 4	12,129,321	12,991,436	14,965,744	18,518,006	7.11%	23.38%	52.67%	0.03%	0.15%	0.27%

Source: M-Five.

The economic impacts are not evenly distributed over the European Union. At country level, the impact depends on CAD investment in relation to GDP or to their total investment; the sectoral structure of their economy; the dependency on trade and trade structure. Most countries benefit from the uptake of CAD depending on the scenario.

Table C.38 Development of GDP per country, Baseline (ASTRA)

	GDP EU27+3 in Mio €2005				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	338,270	359,027	425,003	533,975	7.73%	25.64%	57.85%	0.00%	0.00%	0.00%
BE	407,051	432,029	524,129	708,874	7.73%	28.76%	74.15%	0.00%	0.00%	0.00%
DK	269,140	290,185	353,447	464,164	9.87%	31.32%	72.46%	0.00%	0.00%	0.00%
ES	1,136,973	1,221,072	1,464,058	1,742,217	9.33%	28.77%	53.23%	0.00%	0.00%	0.00%
FI	210,152	221,294	261,436	338,310	6.67%	24.40%	60.98%	0.00%	0.00%	0.00%
FR	2,143,058	2,265,613	2,679,280	3,484,181	7.20%	25.02%	62.58%	0.00%	0.00%	0.00%
UK	2,041,642	2,149,895	2,564,926	3,418,358	6.67%	25.63%	67.43%	0.00%	0.00%	0.00%
DE	2,915,394	3,021,774	3,318,269	3,814,415	4.58%	13.82%	30.84%	0.00%	0.00%	0.00%
EL	201,452	207,977	238,515	288,051	4.06%	18.40%	42.99%	0.00%	0.00%	0.00%
IE	245,369	261,453	312,868	395,027	8.26%	27.51%	60.99%	0.00%	0.00%	0.00%
IT	1,658,517	1,739,570	2,013,053	2,516,783	6.15%	21.38%	51.75%	0.00%	0.00%	0.00%
NL	708,604	737,376	834,957	1,033,646	5.10%	17.83%	45.87%	0.00%	0.00%	0.00%
PT	192,839	204,672	235,213	265,072	7.73%	21.97%	37.46%	0.00%	0.00%	0.00%
SE	406,847	442,114	558,397	766,399	10.95%	37.25%	88.38%	0.00%	0.00%	0.00%
BG	47,813	51,148	60,367	71,131	8.79%	26.26%	48.77%	0.00%	0.00%	0.00%
CH	538,025	586,666	728,567	941,965	11.33%	35.42%	75.08%	0.00%	0.00%	0.00%
CY	20,659	22,274	28,352	40,464	9.87%	37.24%	95.87%	0.00%	0.00%	0.00%
CZ	188,748	202,709	245,451	312,972	9.33%	30.04%	65.82%	0.00%	0.00%	0.00%
EE	20,769	22,130	26,094	31,206	8.26%	25.64%	50.25%	0.00%	0.00%	0.00%
HU	119,480	130,346	160,005	196,137	11.49%	33.92%	64.16%	0.00%	0.00%	0.00%
LV	23,682	25,334	30,049	35,936	8.79%	26.88%	51.74%	0.00%	0.00%	0.00%
LT	36,983	38,029	41,266	48,864	3.55%	11.58%	32.13%	0.00%	0.00%	0.00%
MT	9,519	10,263	12,624	16,256	9.87%	32.62%	70.77%	0.00%	0.00%	0.00%
NO	335,682	368,761	454,258	581,628	12.16%	35.32%	73.27%	0.00%	0.00%	0.00%
PL	440,548	484,387	604,590	715,881	12.59%	37.24%	62.50%	0.00%	0.00%	0.00%
RO	167,738	180,145	214,931	267,392	9.33%	28.13%	59.41%	0.00%	0.00%	0.00%
SI	41,851	44,595	52,323	63,509	8.26%	25.02%	51.75%	0.00%	0.00%	0.00%
SK	79,259	88,171	110,902	126,215	14.25%	39.92%	59.24%	0.00%	0.00%	0.00%
LU	49,524	55,308	75,672	112,295	14.81%	52.80%	126.75%	0.00%	0.00%	0.00%
HR	48,943	51,538	61,487	79,565	6.67%	25.63%	62.57%	0.00%	0.00%	0.00%

Source: M-Five.

Table C.39 Development of GDP per country, Scenario 1 (ASTRA)

	GDP EU27+3 in Mio €2005				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	338,333	359,484	425,548	539,062	7.85%	25.78%	59.33%	0.13%	0.13%	0.95%
BE	406,993	432,155	525,114	714,584	7.78%	29.02%	75.58%	0.04%	0.19%	0.81%
DK	269,083	290,314	353,842	464,217	9.95%	31.50%	72.52%	0.06%	0.11%	0.01%
ES	1,136,701	1,221,859	1,466,343	1,756,035	9.44%	29.00%	54.49%	0.08%	0.16%	0.79%
FI	210,072	221,328	261,723	342,199	6.74%	24.59%	62.90%	0.03%	0.11%	1.15%
FR	2,143,154	2,267,864	2,686,182	3,504,705	7.32%	25.34%	63.53%	0.12%	0.26%	0.59%
UK	2,042,042	2,153,041	2,574,102	3,503,239	6.83%	26.06%	71.56%	0.17%	0.36%	2.48%
DE	2,916,045	3,023,927	3,324,292	3,872,811	4.65%	14.00%	32.81%	0.08%	0.18%	1.53%
EL	201,642	208,571	239,273	289,398	4.30%	18.66%	43.52%	0.32%	0.32%	0.47%
IE	245,400	261,637	312,736	391,540	8.28%	27.44%	59.55%	0.03%	-0.04%	-0.88%
IT	1,658,076	1,740,412	2,015,038	2,529,933	6.24%	21.53%	52.58%	0.06%	0.10%	0.52%
NL	708,911	738,538	837,982	1,046,824	5.22%	18.21%	47.67%	0.16%	0.36%	1.27%
PT	192,645	205,030	236,191	270,591	7.99%	22.60%	40.46%	0.14%	0.42%	2.08%
SE	406,917	442,509	558,926	769,253	11.04%	37.36%	89.04%	0.09%	0.09%	0.37%
BG	47,822	51,201	60,459	71,167	8.91%	26.43%	48.82%	0.12%	0.15%	0.05%
CH	538,061	586,897	730,010	945,784	11.37%	35.67%	75.78%	0.05%	0.20%	0.41%
CY	20,671	22,302	28,418	40,486	10.03%	37.48%	95.86%	0.21%	0.23%	0.05%
CZ	188,771	202,750	246,423	314,565	9.54%	30.54%	66.64%	0.20%	0.40%	0.51%
EE	20,752	22,174	26,141	30,949	8.58%	25.97%	49.13%	0.22%	0.18%	-0.82%
HU	119,601	130,907	161,352	197,312	11.89%	34.91%	64.97%	0.45%	0.84%	0.60%
LV	23,693	25,422	30,143	35,911	9.15%	27.22%	51.57%	0.37%	0.31%	-0.07%
LT	37,026	38,232	41,906	49,243	4.09%	13.18%	32.99%	0.64%	1.55%	0.77%
MT	9,521	10,273	12,638	16,261	9.92%	32.74%	70.79%	0.07%	0.11%	0.03%
NO	335,719	369,049	455,076	583,959	12.25%	35.55%	73.94%	0.09%	0.18%	0.40%
PL	440,723	485,752	612,763	766,970	12.91%	39.04%	74.03%	0.33%	1.35%	7.14%
RO	167,779	180,310	215,702	267,828	9.43%	28.56%	59.63%	0.12%	0.36%	0.16%
SI	41,862	44,671	52,482	63,903	8.44%	25.37%	52.65%	0.19%	0.30%	0.62%
SK	79,323	88,530	111,996	128,660	14.72%	41.19%	62.20%	0.49%	0.99%	1.94%
LU	49,530	55,322	75,711	112,888	14.83%	52.86%	127.92%	0.03%	0.05%	0.53%
HR	48,965	51,635	61,695	79,579	6.83%	26.00%	62.52%	0.19%	0.34%	0.02%

Source: M-Five.

Table C.40 Development of GDP per country, Scenario 2 (ASTRA)

	GDP EU27+3 in Mio €2005				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	338,412	359,604	425,650	536,633	7.85%	25.78%	58.57%	0.16%	0.15%	0.50%
BE	407,043	432,166	525,052	706,854	7.77%	28.99%	73.66%	0.04%	0.18%	-0.28%
DK	269,088	290,393	354,140	460,398	9.99%	31.61%	71.10%	0.09%	0.20%	-0.81%
ES	1,136,738	1,221,978	1,466,460	1,750,442	9.44%	29.01%	53.99%	0.08%	0.16%	0.47%
FI	210,114	221,392	261,863	340,182	6.75%	24.63%	61.90%	0.06%	0.16%	0.55%
FR	2,143,410	2,268,325	2,687,078	3,469,335	7.33%	25.36%	61.86%	0.14%	0.29%	-0.43%
UK	2,042,078	2,153,492	2,575,120	3,420,849	6.86%	26.10%	67.52%	0.20%	0.40%	0.07%
DE	2,918,172	3,026,216	3,326,916	3,851,545	4.65%	14.01%	31.98%	0.16%	0.26%	0.97%
EL	201,643	208,587	239,403	286,580	4.31%	18.73%	42.12%	0.33%	0.37%	-0.51%
IE	245,382	261,631	312,825	394,053	8.35%	27.48%	60.59%	0.09%	-0.01%	-0.25%
IT	1,658,378	1,740,782	2,015,445	2,523,379	6.24%	21.53%	52.16%	0.08%	0.12%	0.26%
NL	708,846	738,588	838,921	1,038,218	5.26%	18.35%	46.47%	0.18%	0.47%	0.44%
PT	192,680	204,938	236,355	269,653	8.00%	22.67%	39.95%	0.17%	0.49%	1.73%
SE	406,946	442,569	559,032	768,309	11.05%	37.37%	88.80%	0.11%	0.11%	0.25%
BG	47,824	51,260	60,558	71,360	9.04%	26.63%	49.21%	0.25%	0.32%	0.32%
CH	538,113	586,957	730,163	943,975	11.37%	35.69%	75.42%	0.06%	0.22%	0.21%
CY	20,667	22,304	28,434	40,433	10.04%	37.58%	95.63%	0.20%	0.29%	-0.08%
CZ	188,780	202,758	246,428	314,364	9.54%	30.54%	66.52%	0.21%	0.40%	0.44%
EE	20,752	22,174	26,142	30,901	8.59%	25.98%	48.91%	0.22%	0.18%	-0.98%
HU	119,632	130,899	161,329	197,341	11.86%	34.85%	64.96%	0.45%	0.83%	0.61%
LV	23,694	25,423	30,142	35,920	9.16%	27.22%	51.60%	0.38%	0.31%	-0.04%
LT	37,022	38,239	41,917	49,049	4.12%	13.22%	32.49%	0.65%	1.58%	0.38%
MT	9,522	10,271	12,639	16,250	9.94%	32.74%	70.66%	0.10%	0.12%	-0.04%
NO	335,719	369,053	455,059	583,273	12.25%	35.55%	73.74%	0.09%	0.18%	0.28%
PL	439,182	484,415	608,221	745,276	12.98%	38.49%	69.70%	0.03%	0.60%	4.11%
RO	167,788	180,439	215,870	267,782	9.49%	28.66%	59.60%	0.18%	0.44%	0.15%
SI	41,864	44,677	52,496	63,749	8.46%	25.40%	52.28%	0.21%	0.33%	0.38%
SK	79,344	88,636	112,389	128,957	14.84%	41.65%	62.53%	0.63%	1.34%	2.17%
LU	49,538	55,332	75,724	112,791	14.83%	52.86%	127.69%	0.05%	0.07%	0.44%
HR	48,980	51,640	61,746	79,123	6.82%	26.06%	61.54%	0.21%	0.42%	-0.56%

Source: M-Five.

Table C.41 Development of GDP per country, Scenario 3 (ASTRA)

	GDP EU27+3 in Mio €2005				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	338,312	359,295	426,186	536,064	7.82%	25.97%	58.45%	0.10%	0.28%	0.39%
BE	406,949	431,848	524,670	695,561	7.72%	28.93%	70.92%	-0.04%	0.10%	-1.88%
DK	269,059	290,218	354,158	464,563	9.93%	31.63%	72.66%	0.03%	0.20%	0.09%
ES	1,136,539	1,220,689	1,465,839	1,741,620	9.35%	28.97%	53.24%	-0.02%	0.12%	-0.03%
FI	210,088	221,237	261,683	339,039	6.69%	24.56%	61.38%	-0.01%	0.09%	0.22%
FR	2,143,013	2,266,233	2,685,801	3,499,312	7.25%	25.33%	63.29%	0.05%	0.24%	0.43%
UK	2,041,686	2,151,669	2,575,420	3,446,067	6.80%	26.14%	68.79%	0.12%	0.41%	0.81%
DE	2,915,939	3,022,656	3,324,359	3,845,314	4.60%	14.01%	31.87%	0.04%	0.18%	0.81%
EL	201,587	208,254	239,521	289,773	4.19%	18.82%	43.75%	0.19%	0.42%	0.60%
IE	245,384	261,476	313,337	394,377	8.27%	27.69%	60.72%	0.02%	0.15%	-0.16%
IT	1,658,193	1,739,870	2,014,917	2,522,211	6.20%	21.51%	52.11%	0.03%	0.09%	0.22%
NL	708,710	737,838	837,876	1,044,971	5.18%	18.23%	47.45%	0.09%	0.35%	1.10%
PT	192,660	204,880	236,168	266,767	7.92%	22.58%	38.47%	0.08%	0.41%	0.64%
SE	406,868	442,197	559,344	767,683	10.99%	37.48%	88.68%	0.04%	0.17%	0.17%
BG	47,811	51,201	60,595	71,269	8.95%	26.74%	49.06%	0.14%	0.38%	0.19%
CH	538,027	586,740	729,587	946,355	11.35%	35.60%	75.89%	0.02%	0.14%	0.47%
CY	20,664	22,287	28,423	40,463	9.94%	37.55%	95.81%	0.09%	0.25%	0.00%
CZ	188,728	202,691	246,105	313,298	9.36%	30.40%	66.00%	0.02%	0.27%	0.10%
EE	20,735	22,084	26,152	30,963	8.25%	26.13%	49.33%	-0.18%	0.22%	-0.78%
HU	119,484	130,376	160,958	196,167	11.57%	34.71%	64.18%	0.07%	0.60%	0.02%
LV	23,679	25,334	30,118	35,938	8.87%	27.19%	51.77%	0.06%	0.23%	0.01%
LT	36,982	38,046	41,838	49,125	3.69%	13.13%	32.83%	0.13%	1.39%	0.53%
MT	9,520	10,265	12,639	16,256	9.89%	32.76%	70.76%	0.04%	0.12%	0.00%
NO	335,689	368,837	455,009	583,086	12.20%	35.54%	73.70%	0.03%	0.17%	0.25%
PL	438,854	483,089	607,703	748,730	12.76%	38.48%	70.61%	-0.23%	0.51%	4.59%
RO	167,780	180,266	215,589	267,936	9.42%	28.49%	59.69%	0.11%	0.31%	0.20%
SI	41,872	44,622	52,472	63,575	8.30%	25.32%	51.83%	0.08%	0.29%	0.10%
SK	79,306	88,291	111,919	127,017	14.40%	41.12%	60.16%	0.19%	0.92%	0.64%
LU	49,538	55,323	75,732	112,601	14.81%	52.88%	127.30%	0.03%	0.08%	0.27%
HR	48,973	51,585	61,732	79,967	6.74%	26.05%	63.29%	0.12%	0.40%	0.51%

Source: M-Five.

Table C.42 Development of GDP per country, Scenario 4 (ASTRA)

	GDP EU27+3 in Mio €2005				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	338,336	359,225	425,464	533,635	7.77%	25.75%	57.72%	0.06%	0.11%	-0.06%
BE	406,997	431,917	523,803	706,189	7.71%	28.70%	73.51%	-0.03%	-0.06%	-0.38%
DK	269,065	290,227	353,990	464,603	9.92%	31.56%	72.67%	0.02%	0.15%	0.09%
ES	1,136,474	1,220,572	1,464,804	1,741,626	9.33%	28.89%	53.25%	-0.04%	0.05%	-0.03%
FI	210,094	221,242	261,468	338,536	6.68%	24.45%	61.14%	-0.02%	0.01%	0.07%
FR	2,143,072	2,266,307	2,684,126	3,492,967	7.24%	25.25%	62.99%	0.04%	0.18%	0.25%
UK	2,041,721	2,151,709	2,574,999	3,441,338	6.78%	26.12%	68.55%	0.11%	0.39%	0.67%
DE	2,917,924	3,024,580	3,324,521	3,819,608	4.59%	13.93%	30.90%	0.10%	0.19%	0.14%
EL	201,588	208,255	239,352	290,253	4.17%	18.73%	43.98%	0.17%	0.35%	0.76%
IE	245,358	261,456	313,212	395,352	8.27%	27.66%	61.13%	0.00%	0.11%	0.08%
IT	1,658,238	1,739,921	2,014,273	2,519,988	6.19%	21.47%	51.97%	0.02%	0.06%	0.13%
NL	708,700	737,832	837,227	1,034,353	5.16%	18.14%	45.95%	0.07%	0.27%	0.07%
PT	192,662	204,885	236,057	266,403	7.91%	22.52%	38.27%	0.08%	0.36%	0.50%
SE	406,885	442,218	559,164	765,807	10.97%	37.43%	88.21%	0.03%	0.14%	-0.08%
BG	47,817	51,205	60,485	71,272	8.93%	26.49%	49.05%	0.13%	0.20%	0.20%
CH	538,077	586,795	729,543	945,679	11.35%	35.58%	75.75%	0.03%	0.13%	0.39%
CY	20,664	22,279	28,398	40,506	9.91%	37.43%	96.02%	0.07%	0.16%	0.10%
CZ	188,746	202,718	245,778	313,189	9.34%	30.22%	65.93%	0.01%	0.13%	0.07%
EE	20,737	22,084	26,078	31,093	8.18%	25.76%	49.94%	-0.23%	-0.06%	-0.36%
HU	119,508	130,388	160,411	196,046	11.48%	34.23%	64.04%	0.01%	0.25%	-0.05%
LV	23,680	25,334	30,069	35,932	8.80%	26.98%	51.74%	-0.01%	0.07%	-0.01%
LT	36,980	38,045	41,573	49,219	3.61%	12.42%	33.09%	0.06%	0.74%	0.73%
MT	9,521	10,265	12,636	16,261	9.88%	32.72%	70.80%	0.03%	0.09%	0.04%
NO	335,691	368,839	454,778	582,263	12.19%	35.48%	73.45%	0.03%	0.11%	0.11%
PL	438,880	483,129	606,061	744,588	12.72%	38.09%	69.66%	-0.26%	0.24%	4.01%
RO	167,726	180,252	215,426	267,752	9.41%	28.44%	59.64%	0.07%	0.23%	0.13%
SI	41,852	44,601	52,409	63,532	8.28%	25.22%	51.80%	0.02%	0.16%	0.04%
SK	79,310	88,301	111,569	126,931	14.37%	40.67%	60.04%	0.17%	0.60%	0.57%
LU	49,536	55,322	75,721	112,612	14.81%	52.86%	127.33%	0.03%	0.06%	0.28%
HR	48,971	51,580	61,670	79,756	6.68%	25.93%	62.86%	0.07%	0.30%	0.24%

Source: M-Five.

Impact of CAD on total employment

The tables below present the results of absolute total employment in persons, the percentage change of employment against the baseline as well as against the base year 2020 for EU27 as well as on country level.

Table C.43 Total employment of EU27, all scenarios (ASTRA)

	Total Employment in Persons				% Change to 2020			% Change to Base		
Scenario	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
Baseline	199,113,824	197,200,608	193,374,400	188,866,304	-0.96%	-2.88%	-5.15%	0.00%	0.00%	0.00%
Scenario 1	198,986,256	197,165,200	193,490,832	188,216,960	-0.92%	-2.76%	-5.41%	-0.02%	0.06%	-0.34%
Scenario 2	198,989,056	197,220,560	193,476,544	188,022,592	-0.89%	-2.77%	-5.51%	0.01%	0.05%	-0.45%
Scenario 3	198,981,472	197,180,736	193,395,776	188,532,000	-0.90%	-2.81%	-5.25%	-0.01%	0.01%	-0.18%
Scenario 4	198,981,312	197,173,696	193,334,880	188,812,160	-0.91%	-2.84%	-5.11%	-0.01%	-0.02%	-0.03%

Source: M-Five.

Table C.44 Development of total employment per country, Baseline (ASTRA)

	Total Employment EU27+3 in Persons				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	4,430,919	4,429,869	4,413,736	4,436,292	-0.01%	-0.39%	0.12%	0.00%	0.00%	0.00%
BE	4,766,248	4,791,428	4,904,703	5,248,051	0.68%	2.90%	10.11%	0.00%	0.00%	0.00%
DK	2,913,072	2,917,710	2,957,931	3,073,272	0.25%	1.54%	5.50%	0.00%	0.00%	0.00%
ES	19,413,664	19,407,176	19,336,212	19,319,854	-0.06%	-0.40%	-0.48%	0.00%	0.00%	0.00%
FI	2,575,752	2,566,539	2,515,184	2,480,063	-0.51%	-2.35%	-3.72%	0.00%	0.00%	0.00%
FR	24,393,298	24,321,044	24,063,396	24,201,070	-0.39%	-1.35%	-0.79%	0.00%	0.00%	0.00%
UK	32,433,678	32,346,822	31,511,200	31,146,720	-0.43%	-2.84%	-3.97%	0.00%	0.00%	0.00%
DE	43,225,312	42,996,416	42,288,960	41,467,432	-0.66%	-2.17%	-4.07%	0.00%	0.00%	0.00%
EL	3,949,944	3,767,288	3,309,690	2,864,605	-5.78%	-16.21%	-27.48%	0.00%	0.00%	0.00%
IE	2,256,745	2,242,785	2,228,495	2,203,570	-0.81%	-1.25%	-2.36%	0.00%	0.00%	0.00%
IT	23,696,750	23,106,966	21,853,314	20,609,168	-3.07%	-7.78%	-13.03%	0.00%	0.00%	0.00%
NL	8,754,342	8,741,758	8,715,012	8,770,091	-0.17%	-0.45%	0.18%	0.00%	0.00%	0.00%
PT	4,905,940	4,822,741	4,629,175	4,411,492	-2.10%	-5.64%	-10.08%	0.00%	0.00%	0.00%
SE	5,174,575	5,222,537	5,357,301	5,566,825	1.15%	3.53%	7.58%	0.00%	0.00%	0.00%
BG	3,144,473	3,015,117	2,614,675	2,099,984	-5.26%	-16.85%	-33.22%	0.00%	0.00%	0.00%
CH	4,938,618	4,940,671	4,938,692	5,057,153	0.06%	0.00%	2.40%	0.00%	0.00%	0.00%
CY	410,445	411,676	417,862	428,906	0.43%	1.81%	4.50%	0.00%	0.00%	0.00%
CZ	5,299,143	5,200,747	5,000,814	4,827,377	-2.35%	-5.63%	-8.90%	0.00%	0.00%	0.00%
EE	666,273	661,276	638,070	595,679	-0.85%	-4.23%	-10.60%	0.00%	0.00%	0.00%
HU	4,665,264	4,662,163	4,698,494	4,546,692	0.37%	0.71%	-2.54%	0.00%	0.00%	0.00%
LV	1,006,354	967,586	880,361	762,150	-4.51%	-12.52%	-24.27%	0.00%	0.00%	0.00%
LT	1,525,152	1,485,439	1,324,822	1,046,610	-3.40%	-13.14%	-31.38%	0.00%	0.00%	0.00%
MT	230,399	232,401	236,116	245,615	0.95%	2.48%	6.60%	0.00%	0.00%	0.00%
NO	2,538,939	2,532,903	2,548,022	2,561,568	-0.27%	0.36%	0.89%	0.00%	0.00%	0.00%
PL	17,067,888	17,314,618	17,618,904	17,743,622	1.68%	3.23%	3.96%	0.00%	0.00%	0.00%
RO	9,024,821	8,701,625	8,035,269	6,925,351	-3.99%	-10.96%	-23.26%	0.00%	0.00%	0.00%
SI	978,613	956,625	898,712	826,157	-2.78%	-8.16%	-15.58%	0.00%	0.00%	0.00%
SK	2,586,324	2,588,212	2,533,959	2,397,033	-0.04%	-2.02%	-7.32%	0.00%	0.00%	0.00%
LU	291,194	291,927	291,088	289,185	0.28%	-0.04%	-0.69%	0.00%	0.00%	0.00%
HR	1,760,928	1,728,907	1,612,141	1,480,151	-2.38%	-8.45%	-15.94%	0.00%	0.00%	0.00%

Source: M-Five.

Table C.45 Development of total employment per country, Scenario 1 (ASTRA)

	Total Employment EU27+3 in Persons				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	4,427,714	4,428,836	4,416,189	4,418,730	0.04%	-0.26%	-0.20%	-0.01%	0.06%	-0.40%
BE	4,769,505	4,795,806	4,913,280	5,221,718	0.71%	3.01%	9.48%	0.09%	0.17%	-0.50%
DK	2,905,194	2,911,680	2,954,371	3,054,301	0.32%	1.69%	5.13%	-0.20%	-0.12%	-0.62%
ES	19,367,712	19,367,020	19,309,800	19,248,214	-0.03%	-0.30%	-0.62%	-0.20%	-0.14%	-0.37%
FI	2,563,109	2,552,836	2,500,556	2,449,468	-0.56%	-2.44%	-4.43%	-0.54%	-0.58%	-1.23%
FR	24,340,640	24,278,886	24,041,216	24,059,778	-0.34%	-1.23%	-1.15%	-0.17%	-0.09%	-0.58%
UK	32,389,336	32,316,258	31,508,470	31,177,420	-0.38%	-2.72%	-3.74%	-0.09%	-0.01%	0.10%
DE	43,285,712	43,069,280	42,403,944	41,475,432	-0.62%	-2.04%	-4.18%	0.18%	0.27%	0.02%
EL	3,980,662	3,799,895	3,338,825	2,882,889	-5.69%	-16.1%	-27.6%	0.88%	0.88%	0.64%
IE	2,256,817	2,242,373	2,222,931	2,185,372	-0.84%	-1.50%	-3.17%	-0.02%	-0.25%	-0.83%
IT	23,623,338	23,048,138	21,807,534	20,525,964	-3.00%	-7.69%	-13.1%	-0.24%	-0.21%	-0.40%
NL	8,751,308	8,740,848	8,720,296	8,738,846	-0.14%	-0.35%	-0.14%	-0.01%	0.06%	-0.36%
PT	4,887,869	4,804,506	4,612,934	4,392,594	-2.11%	-5.62%	-10.1%	-0.37%	-0.35%	-0.43%
SE	5,174,777	5,223,702	5,361,780	5,547,117	1.17%	3.61%	7.20%	0.02%	0.08%	-0.35%
BG	3,144,421	3,017,347	2,618,154	2,084,810	-5.18%	-16.7%	-33.7%	0.08%	0.13%	-0.72%
CH	4,937,252	4,939,988	4,941,852	5,041,004	0.07%	0.09%	2.10%	-0.01%	0.06%	-0.32%
CY	410,419	411,783	417,880	427,989	0.46%	1.82%	4.28%	0.03%	0.00%	-0.21%
CZ	5,299,380	5,202,674	5,008,921	4,780,234	-2.32%	-5.48%	-9.80%	0.04%	0.16%	-0.98%
EE	657,870	652,570	629,116	582,805	-0.92%	-4.37%	-11.4%	-1.33%	-1.40%	-2.16%
HU	4,665,537	4,664,886	4,704,712	4,506,550	0.42%	0.84%	-3.41%	0.06%	0.13%	-0.88%
LV	1,001,704	963,997	877,085	757,451	-4.41%	-12.4%	-24.4%	-0.36%	-0.37%	-0.62%
LT	1,525,272	1,487,114	1,329,235	1,044,713	-3.28%	-12.9%	-31.5%	0.13%	0.33%	-0.18%
MT	230,398	232,417	236,134	245,367	0.96%	2.49%	6.50%	0.01%	0.01%	-0.10%
NO	2,539,012	2,533,259	2,548,102	2,548,507	-0.26%	0.36%	0.37%	0.01%	0.00%	-0.51%
PL	17,068,700	17,330,780	17,676,868	17,738,848	1.79%	3.56%	3.93%	0.11%	0.33%	-0.03%
RO	9,025,266	8,701,670	8,040,969	6,865,994	-4.00%	-10.9%	-23.9%	0.00%	0.07%	-0.86%
SI	978,244	956,698	899,921	819,824	-2.73%	-8.01%	-16.2%	0.01%	0.13%	-0.77%
SK	2,592,503	2,595,664	2,544,273	2,393,190	0.02%	-1.86%	-7.69%	0.30%	0.41%	-0.16%
LU	291,194	291,941	291,145	289,347	0.29%	-0.02%	-0.63%	0.01%	0.02%	0.06%
HR	1,761,002	1,729,363	1,612,769	1,479,390	-2.36%	-8.42%	-16.0%	0.03%	0.04%	-0.05%

Source: M-Five.

Table C.46 Development of total employment per country, Scenario 2 (ASTRA)

	Total Employment EU27+3 in Persons				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	4,428,060	4,429,417	4,415,144	4,415,002	0.05%	-0.29%	-0.29%	0.00%	0.03%	-0.48%
BE	4,769,827	4,794,502	4,911,310	5,263,751	0.70%	2.97%	10.36%	0.09%	0.13%	0.30%
DK	2,905,316	2,911,984	2,954,094	3,048,289	0.33%	1.68%	4.92%	-0.18%	-0.13%	-0.81%
ES	19,368,366	19,367,986	19,304,168	19,276,350	-0.03%	-0.33%	-0.48%	-0.20%	-0.17%	-0.23%
FI	2,563,237	2,552,958	2,499,990	2,448,880	-0.56%	-2.47%	-4.46%	-0.53%	-0.60%	-1.26%
FR	24,341,662	24,280,036	24,035,072	23,993,148	-0.34%	-1.26%	-1.43%	-0.16%	-0.12%	-0.86%
UK	32,390,996	32,320,220	31,506,300	30,920,408	-0.37%	-2.73%	-4.54%	-0.07%	-0.02%	-0.73%
DE	43,285,688	43,071,228	42,392,552	41,425,264	-0.62%	-2.06%	-4.30%	0.18%	0.24%	-0.10%
EL	3,980,833	3,800,209	3,338,859	2,870,137	-5.68%	-16.13%	-27.90%	0.89%	0.88%	0.19%
IE	2,256,866	2,243,018	2,222,874	2,190,280	-0.81%	-1.51%	-2.95%	0.01%	-0.25%	-0.60%
IT	23,624,084	23,048,374	21,803,436	20,499,934	-3.00%	-7.71%	-13.22%	-0.24%	-0.23%	-0.53%
NL	8,751,745	8,741,293	8,723,338	8,722,395	-0.14%	-0.32%	-0.34%	0.00%	0.10%	-0.54%
PT	4,887,951	4,804,574	4,612,736	4,386,870	-2.11%	-5.63%	-10.25%	-0.37%	-0.36%	-0.56%
SE	5,174,780	5,223,848	5,360,931	5,541,600	1.18%	3.60%	7.09%	0.03%	0.07%	-0.45%
BG	3,144,534	3,056,896	2,652,976	2,107,565	-3.80%	-15.63%	-32.98%	1.54%	1.46%	0.36%
CH	4,937,450	4,940,296	4,941,370	5,038,053	0.08%	0.08%	2.04%	0.00%	0.05%	-0.38%
CY	410,416	411,820	417,889	427,389	0.46%	1.82%	4.14%	0.03%	0.01%	-0.35%
CZ	5,299,401	5,202,873	5,006,551	4,771,505	-2.31%	-5.53%	-9.96%	0.05%	0.11%	-1.16%
EE	657,905	652,658	628,943	582,155	-0.91%	-4.40%	-11.51%	-1.32%	-1.43%	-2.27%
HU	4,665,576	4,664,787	4,702,960	4,501,809	0.42%	0.80%	-3.51%	0.06%	0.10%	-0.99%
LV	1,001,755	964,080	876,870	756,801	-4.40%	-12.47%	-24.45%	-0.35%	-0.40%	-0.70%
LT	1,525,320	1,487,210	1,328,928	1,043,291	-3.28%	-12.88%	-31.60%	0.14%	0.31%	-0.32%
MT	230,404	232,423	236,137	245,248	0.96%	2.49%	6.44%	0.01%	0.01%	-0.15%
NO	2,539,006	2,533,331	2,547,530	2,546,487	-0.26%	0.34%	0.29%	0.01%	-0.02%	-0.59%
PL	17,067,612	17,332,654	17,665,028	17,675,720	1.81%	3.50%	3.56%	0.12%	0.26%	-0.38%
RO	9,024,940	8,702,855	8,040,151	6,854,354	-3.98%	-10.91%	-24.05%	0.01%	0.06%	-1.03%
SI	978,323	956,832	899,638	817,974	-2.73%	-8.04%	-16.39%	0.03%	0.10%	-0.99%
SK	2,592,638	2,596,229	2,544,458	2,391,095	0.04%	-1.86%	-7.77%	0.32%	0.41%	-0.25%
LU	291,193	291,941	291,134	289,291	0.29%	-0.02%	-0.65%	0.01%	0.02%	0.04%
HR	1,760,606	1,728,265	1,610,402	1,476,508	-2.40%	-8.53%	-16.14%	-0.04%	-0.11%	-0.25%

Source: M-Five.

Table C.47 Development of total employment per country, Scenario 3 (ASTRA)

	Total Employment EU27+3 in Persons				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	4,427,975	4,428,576	4,416,093	4,417,538	0.03%	-0.27%	-0.24%	-0.02%	0.05%	-0.42%
BE	4,769,736	4,793,976	4,907,133	5,244,406	0.69%	2.88%	9.95%	0.08%	0.05%	-0.07%
DK	2,905,256	2,911,699	2,953,061	3,061,437	0.32%	1.65%	5.38%	-0.19%	-0.16%	-0.39%
ES	19,367,312	19,362,214	19,293,298	19,320,962	-0.05%	-0.38%	-0.24%	-0.22%	-0.22%	0.01%
FI	2,563,155	2,552,569	2,499,812	2,455,982	-0.57%	-2.47%	-4.18%	-0.54%	-0.61%	-0.97%
FR	24,340,212	24,273,886	24,026,052	24,112,710	-0.36%	-1.29%	-0.93%	-0.18%	-0.16%	-0.37%
UK	32,390,106	32,313,032	31,496,038	31,116,782	-0.39%	-2.76%	-3.93%	-0.09%	-0.05%	-0.10%
DE	43,284,892	43,065,580	42,396,264	41,460,784	-0.63%	-2.05%	-4.21%	0.17%	0.25%	-0.02%
EL	3,980,702	3,799,017	3,337,856	2,882,454	-5.71%	-16.2%	-27.6%	0.86%	0.85%	0.62%
IE	2,256,711	2,242,288	2,225,883	2,200,119	-0.84%	-1.37%	-2.51%	-0.03%	-0.12%	-0.16%
IT	23,623,536	23,045,666	21,796,482	20,536,072	-3.01%	-7.73%	-13.1%	-0.25%	-0.26%	-0.35%
NL	8,751,814	8,740,038	8,716,341	8,745,742	-0.15%	-0.41%	-0.07%	-0.01%	0.02%	-0.28%
PT	4,887,809	4,804,009	4,611,720	4,390,183	-2.11%	-5.65%	-10.2%	-0.38%	-0.38%	-0.48%
SE	5,174,565	5,223,062	5,361,613	5,549,991	1.17%	3.61%	7.26%	0.02%	0.08%	-0.30%
BG	3,144,447	3,054,546	2,648,853	2,114,660	-3.86%	-15.8%	-32.8%	1.48%	1.31%	0.70%
CH	4,937,421	4,939,991	4,938,367	5,049,529	0.07%	0.02%	2.27%	-0.01%	-0.01%	-0.15%
CY	410,404	411,709	417,894	427,199	0.45%	1.83%	4.09%	0.01%	0.01%	-0.40%
CZ	5,299,046	5,201,876	4,999,504	4,799,559	-2.32%	-5.65%	-9.43%	0.03%	-0.03%	-0.58%
EE	657,822	652,219	628,419	584,360	-0.95%	-4.47%	-11.2%	-1.38%	-1.51%	-1.90%
HU	4,665,168	4,663,543	4,697,130	4,518,379	0.41%	0.69%	-3.15%	0.04%	-0.03%	-0.62%
LV	1,001,606	963,263	876,500	757,629	-4.46%	-12.5%	-24.4%	-0.42%	-0.44%	-0.59%
LT	1,525,207	1,486,008	1,327,668	1,045,292	-3.35%	-13.0%	-31.5%	0.06%	0.21%	-0.13%
MT	230,393	232,411	236,137	245,570	0.96%	2.49%	6.59%	0.01%	0.01%	-0.02%
NO	2,538,924	2,532,979	2,547,749	2,552,685	-0.26%	0.35%	0.54%	0.00%	-0.01%	-0.35%
PL	17,066,514	17,325,738	17,649,496	17,775,052	1.77%	3.42%	4.15%	0.08%	0.17%	0.18%
RO	9,024,605	8,700,902	8,029,970	6,900,545	-3.99%	-11.0%	-23.5%	0.00%	-0.07%	-0.36%
SI	978,284	956,678	898,575	821,570	-2.73%	-8.15%	-16.0%	0.02%	-0.02%	-0.56%
SK	2,592,544	2,595,131	2,541,802	2,394,395	-0.01%	-1.96%	-7.64%	0.28%	0.31%	-0.11%
LU	291,191	291,931	291,107	289,316	0.29%	-0.03%	-0.64%	0.00%	0.01%	0.05%
HR	1,760,564	1,728,323	1,611,107	1,480,091	-2.39%	-8.49%	-15.9%	-0.03%	-0.06%	0.00%

Source: M-Five.

Table C.48 Development of total employment per country, Scenario 4 (ASTRA)

	Total Employment EU27+3 in Persons				% Change to 2020			% Change to Baseline		
	2020	2025	2035	2050	2025	2035	2050	2025	2035	2050
AT	4,427,975	4,428,381	4,411,763	4,416,649	0.03%	-0.37%	-0.26%	-0.02%	-0.04%	-0.44%
BE	4,769,745	4,793,965	4,906,638	5,276,187	0.69%	2.87%	10.62%	0.08%	0.04%	0.54%
DK	2,905,257	2,911,703	2,952,825	3,067,062	0.32%	1.64%	5.57%	-0.20%	-0.17%	-0.20%
ES	19,367,378	19,361,958	19,290,628	19,349,488	-0.06%	-0.40%	-0.09%	-0.23%	-0.24%	0.15%
FI	2,563,158	2,552,571	2,498,584	2,453,912	-0.57%	-2.52%	-4.26%	-0.55%	-0.66%	-1.05%
FR	24,340,218	24,273,916	24,023,042	24,168,704	-0.36%	-1.30%	-0.70%	-0.19%	-0.17%	-0.13%
UK	32,390,128	32,313,084	31,494,668	31,169,674	-0.39%	-2.76%	-3.77%	-0.10%	-0.05%	0.07%
DE	43,284,872	43,065,488	42,369,032	41,437,708	-0.63%	-2.12%	-4.27%	0.17%	0.19%	-0.07%
EL	3,980,699	3,799,082	3,337,467	2,892,754	-5.71%	-16.16%	-27.33%	0.86%	0.84%	0.98%
IE	2,256,758	2,242,364	2,225,925	2,201,638	-0.84%	-1.37%	-2.44%	-0.02%	-0.12%	-0.09%
IT	23,623,548	23,045,688	21,795,346	20,570,048	-3.01%	-7.74%	-12.93%	-0.25%	-0.27%	-0.19%
NL	8,751,542	8,739,798	8,712,056	8,736,932	-0.15%	-0.45%	-0.17%	-0.02%	-0.03%	-0.38%
PT	4,887,805	4,804,007	4,611,462	4,394,440	-2.12%	-5.65%	-10.09%	-0.38%	-0.38%	-0.39%
SE	5,174,567	5,223,080	5,359,745	5,546,153	1.17%	3.58%	7.18%	0.01%	0.05%	-0.37%
BG	3,144,368	3,054,268	2,648,198	2,124,454	-3.86%	-15.78%	-32.44%	1.47%	1.28%	1.17%
CH	4,937,412	4,939,996	4,938,158	5,057,874	0.07%	0.02%	2.44%	-0.01%	-0.01%	0.01%
CY	410,404	411,708	417,766	428,093	0.44%	1.79%	4.31%	0.00%	-0.02%	-0.19%
CZ	5,299,080	5,201,926	4,998,316	4,822,853	-2.33%	-5.68%	-8.99%	0.03%	-0.05%	-0.09%
EE	657,830	652,221	628,140	586,425	-0.97%	-4.51%	-10.85%	-1.39%	-1.56%	-1.55%
HU	4,665,194	4,663,133	4,695,502	4,541,822	0.39%	0.65%	-2.64%	0.03%	-0.06%	-0.11%
LV	1,001,607	963,262	876,235	759,491	-4.47%	-12.52%	-24.17%	-0.44%	-0.47%	-0.35%
LT	1,525,203	1,486,004	1,326,663	1,047,582	-3.35%	-13.02%	-31.32%	0.05%	0.14%	0.09%
MT	230,399	232,395	236,113	245,598	0.95%	2.48%	6.60%	0.00%	0.00%	-0.01%
NO	2,538,928	2,532,970	2,546,678	2,551,427	-0.27%	0.31%	0.49%	0.00%	-0.05%	-0.40%
PL	17,066,652	17,325,668	17,644,070	17,828,984	1.77%	3.38%	4.47%	0.08%	0.14%	0.48%
RO	9,024,488	8,701,645	8,028,881	6,917,938	-3.98%	-11.03%	-23.34%	0.00%	-0.08%	-0.11%
SI	978,274	956,562	898,602	825,432	-2.75%	-8.14%	-15.62%	0.00%	-0.01%	-0.09%
SK	2,592,553	2,595,165	2,540,868	2,401,456	-0.01%	-1.99%	-7.37%	0.27%	0.27%	0.18%
LU	291,193	291,934	291,113	289,356	0.29%	-0.03%	-0.63%	0.00%	0.01%	0.06%
HR	1,760,535	1,727,934	1,609,889	1,481,008	-2.42%	-8.56%	-15.88%	-0.06%	-0.14%	0.06%

Source: M-Five.

Detailed modelling results on employment impacts in NEMESIS

Methodology

In order to simulate the macroeconomic impact of Connected an Automated Driving (CAD), NEMESIS received data from two sources: All those directly concerning the CAD development are coming from the Scenario model developed by TRT, and those related to investment in infrastructure are received from ASTRA (M-Five).

Regarding the development of CAD, we integrate in the NEMESIS model all data concerning expenditures:

- by firms (bus, commercial cars, trucks) as investment realised by land transport services;
- by households, i.e. the purchase of cars (considered as final consumption in the national accounts) as well as the expenditure in the different transport modes (train, taxi, robotaxi etc.) with regard to their different consumption categories.
  (NEMESIS considers 27 consumption categories).

Infrastructure and other investment are allocated to the corresponding sector (of the 30 sectors) of NEMESIS.

These shocks are introduced in the NEMESIS model which computes direct and indirect socio-economic impacts through its macroeconomic and inter-sectoral framework. Most of the results presented below are expressed in difference (in level or percentage) with respect to a reference Scenario (baseline), or in terms of GDP contributions. It allows direct assessment of the macro-economic impacts in the four CAD deployment Scenarios.

Employment and macroeconomic results by NEMESIS

Scenario 1

Two main characteristics of *Scenario 1* drive the macroeconomic impacts in the NEMESIS model: (*i*) a relatively early arrival of the CAD on the market, as level 5 vehicles are assumed entering into the market in 2035, and (*ii*) a low regulation, as automated vehicles can operate without any restriction both in urban and rural areas.

These characteristics entail a quick and large deployment of CAD in the EU thanks to upstream infrastructure investments and firms' replacement of their trucks and car fleet, requiring new investments. Hence firms face no barrier to develop their CAD fleet and can invest freely. Consequently, the investment increased by +0.83% in 2050 (see Table C.49). However, the impact on employment in the Land Transport Sector, is high with a loss of almost 50% jobs (-2,276 thousand with respect to the baseline in 2050), while other sectors see their employment increase, benefiting from the development and investment in CAD (mainly Electronics and Transport Equipment sectors). But at the macroeconomic level employment slightly decreases by 0.46% (-967 thousand). Final households' consumption is not much affected by the decrease of employment because of the slight price decrease following productivity gains (see below).

The development of CAD leads in NEMESIS to relatively high productivity gains with respect to the rest of the World that explains the strong positive contribution of export (+1.93% with respect to the baseline). But this point needs to be put in perspective as we do not make any assumptions regarding the development of CAD in the countries outside the EU (except United-Kingdom, Norway and Switzerland). If we suppose that other countries follow more or less the same pace, this positive contribution may be lower.

Table C.49 Main macroeconomic results for Scenario 1 (NEMESIS)

	2030	2040	2050
GDP	0.01%	-0.02%	0.89%
Final Consumption	0.04% (0.02%)	-0.05% (-0.03%)	-0.03% (-0.02%)
Investment	0.22% (0.05%)	-0.15% (-0.03%)	0.83% (0.20%)
Exports	-0.15% (-0.05%)	0.07% (0.03%)	1.93% (0.73%)
Imports	0.04% (-0.01%)	-0.06% (0.02%)	0.04% (-0.02%)
Total Employment	0.02% (40)	-0.10% (-215)	-0.46% (-967)

% deviation with respect to baseline, GDP contribution (in brackets), Employment deviation in level (thousands).
Source: SEURECO.

Table C.50 Employment in some sectors for Scenario 1 (NEMESIS)

	2030	2040	2050
Electrical Equipment (Incl. Electronics)	-0.08% (-1.5)	0.03% (0.6)	1.49% (29)
Transports Equipment	0.00% (-0.1)	-0.08% (-2.4)	1.76% (53.2)
Construction	0.10% (12.7)	-0.06% (-7)	0.64% (-64.3)
Land Transports	0.55% (23.1)	-3.81% (-191.6)	-49.19% (-2276.2)
Other market Services	-0.01% (-2.6)	-0.01% (-3.71)	-49.19% (-2276.2)

% deviation with respect to baseline, Employment deviation in level (thousands).
Source: SEURECO.

Scenario 2

In *Scenario 2* (, similar to *Scenario 1*,) the availability of the automated vehicles (Level 5) is relatively early, in 2035. However, in this scenario, local and national authorities impose stronger limitations to the circulation of fully automated vehicles. Consequently, it will limit the benefits of investment in CAD and then their penetration rate on the market.

These higher regulations will limit the penetration of CAD into the market and explains the lower GDP gains (+0.34%) when compared to the first scenario (+0.89%). This difference can be explained by the fact that even if final consumption contribution remains almost zero, total investment is lower than in Scenario 1 (+0.33% instead of +0.83% compared to the baseline). This smaller investment in CAD benefits to employment in the Land Transport sector in which the decrease of jobs is far less important than is Scenario 1 (-10.75% with respect to baseline, -497.5 thousand), leading to a relatively unchanged total employment compared to the baseline (+13 thousand). All these factors lead to much lower productivity gains in NEMESIS and a less important increase of external trade gains.

Table C.51 Main macroeconomic results for Scenario 2 (NEMESIS)

	2030	2040	2050
GDP	0.06%	0.00%	0.34%
Final Consumption	0.04% (0.02%)	-0.04% (-0.02%)	0.04% (0.02%)
Investment	0.28% (0.06%)	-0.12% (-0.03%)	0.33% (0.08%)
Exports	-0.01% (0.00%)	0.09% (0.04%)	0.68% (0.25%)
Imports	0.06% (-0.02%)	-0.05% (0.01%)	0.05% (-0.02%)
Total Employment	0.06% (121)	-0.07% (-159)	0.01% (+13)

% deviation with respect to baseline, GDP contribution (in brackets), Employment deviation in level (thousands).
Source: SEURECO.

Table C.52 Employment in some sectors for Scenario 2 (NEMESIS)

	2030	2040	2050
Electrical Equipment (Incl. Electronics)	0.04% (0.6)	0.04% (0.8)	0.57% (11.1)
Transports Equipment	0.15% (4.9)	-0.04% (-1.4)	0.68% (21.7)
Construction	0.15% (19.1)	-0.03% (-3.3)	0.31% (28.7)
Land Transports	0.47% (25.3)	-3.17% (-159.9)	-10.75% (-497.5)
Other market Services	0.06% (22.6)	0.02% (5.9)	0.36% (139.7)

% deviation with respect to baseline, Employment deviation in level (thousands).
Source: SEURECO.

Scenario 3

In this Scenario, level 5 vehicles arrive a bit later than in the previous ones (2040) and regulations are implemented which lower their penetration. Moreover, the mobility is shared and the number of forerunners is less important. Compared to Scenario 1, GDP gains are almost the same (+0.89% compared to baseline, see Table C.53).

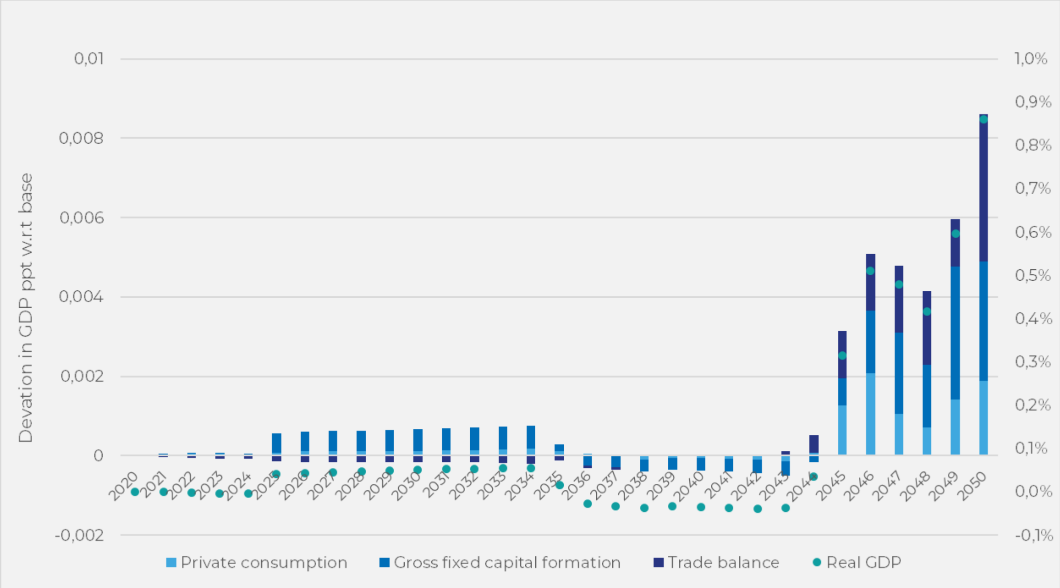
Table C.53 Main macroeconomic results for Scenario 3 (NEMESIS)

	2030	2040	2050
GDP	0.05%	-0.04%	0.89%
Final Consumption	0.02% (0.01%)	-0.01% (-0.01%)	0.36% (0.18%)
Investment	0.24% (0.05%)	-0.14% (-0.03%)	1.32% (0.32%)
Exports	0.00% (0.00%)	-0.01% (0.00%)	1.13% (0.43%)
Imports	0.05% (-0.01%)	-0.02% (0.01%)	0.11% (-0.04%)
Total Employment	0.04% (94)	-0.01% (-16)	-0.22% (-470)

% deviation with respect to baseline, GDP contribution (in brackets), Employment deviation in level (thousands).
Source: SEURECO.

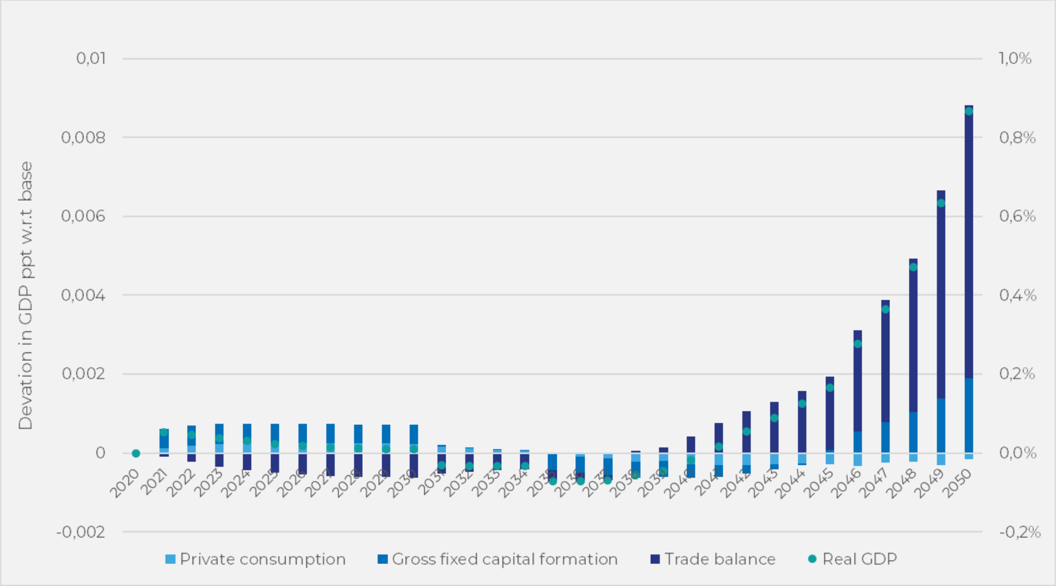
However, looking at GDP contributions we can see that the main factors leading to this GDP increase are very different (Figure C.18 and Figure C.19). Indeed, the contribution to GDP of investment is more important in Scenario 3 (0.32%) than in Scenario 1 (0.20%). This can be explained by the importance of shared mobility in the third scenario. The transport services sectors need to invest more to meet the demand for shared services, while for private mobility cars are bought at the charge of households. We can also note the positive contribution of final households' consumption in Scenario 3 (+0.18% of GDP), while it is almost zero in the first one. The number of forerunners being lower added to the regulation imposed, lead to a less important development of CAD in Scenario 3 and to less employment loss.

Figure C.18 GDP and its contributions for Scenario 3 (NEMESIS)



GDP in % deviation with respect to baseline.
Source: SEURECO.

Figure C.19 GDP and its contributions for Scenario 1 (NEMESIS)



GDP in % deviation with respect to baseline.
Source: SEURECO.

Regarding sectoral employment we can see in Table C.54 that the employment in land transport services is less impacted compared to the two preceding scenarios. The first reason is that the forerunner countries are less important and as a consequence the development of CAD level 5 vehicles all over Europe is slower than in Scenario 1 and 2. Secondly, the arrival of level 5 vehicles in the market is set to be later compared to both previous scenarios. They have less time to spread all over the economy.

Table C.54 Employment in some sectors for Scenario 3 (NEMESIS)

	2030	2040	2050
Electrical Equipment (Incl. Electronics)	0.04% (0.6)	-0.01% (-0.2)	1.09% (21)
Transports Equipment	0.14% (4.5)	-0.09% (-2.8)	2.42% (77)
Construction	0.11% (14.1)	-0.03% (-3.8)	0.8% (-74.2)
Land Transports	0.38% (20.4)	0.16% (7.8)	-7.55% (-349.5)
Other market Services	0.04% (15.7)	-0.00% (-1.5)	-0.11% (-44)

% deviation with respect to baseline, Employment deviation in level (thousands).
Source: SEURECO.

Scenario 4

In this scenario, the CAD level 5 vehicles arrive late in the market (2045), but regulations imposed are less important than in Scenario 3. GDP gains are less important than in the Scenario 3 (+0.31% with respect to baseline, Table C.55), comparable to Scenario 2 (+0.34%). But comparing to Scenario 2 the main impulses to GDP gains are quite different.

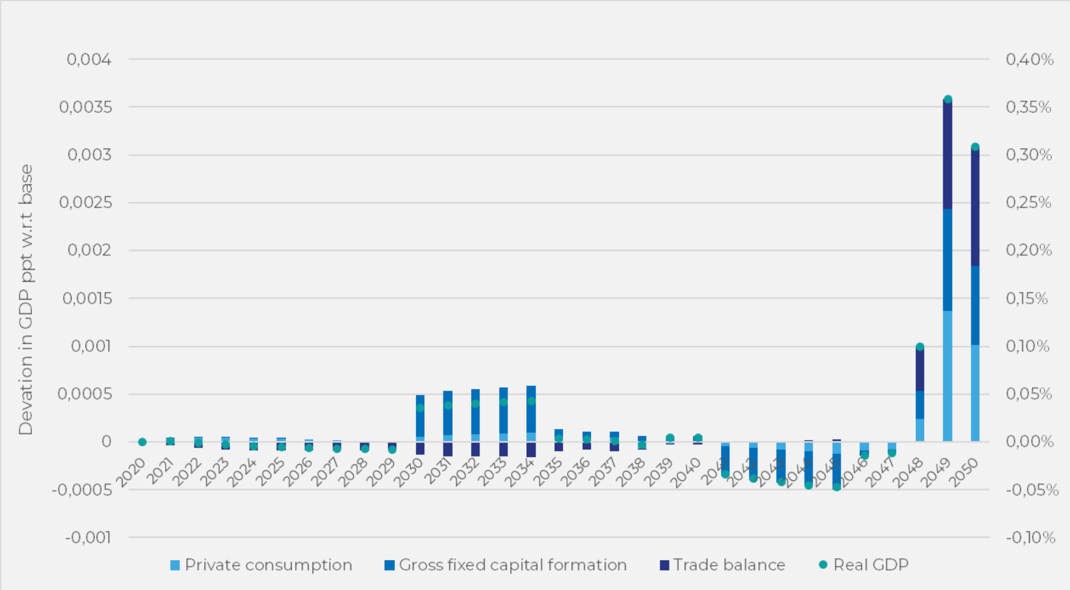
Table C.55 Main macroeconomic results for Scenario 4 (NEMESIS)

	2030	2040	2050
GDP	0.04%	0.00%	0.31%
Final Consumption	0.01% (0.01%)	0.00% (0.00%)	0.18% (0.10%)
Investment	0.19% (0.04%)	0.03% (0.01%)	0.36% (0.08%)
Exports	-0.01% (0.00%)	0.00% (0.00%)	0.36% (0.13%)
Imports	0.03% (-0.01%)	0.01% (0.00%)	0.00% (0.00%)
Total Employment	0.03% (62)	0.01% (26)	-0.07% (-150)

% deviation with respect to baseline, GDP contribution (in brackets), Employment deviation in level (thousands).
Source: SEURECO.

Investment contribution (see Figure C.20 and Figure C.21) remains the same in both scenarios in 2050 (0.08% of GDP). However, these investments are of different kind. In Scenario 4, the assumption of shared mobility increases investments to meet the demand of households', while in Scenario 2 they are more freight-oriented. Moreover, the fact that there are less forerunners in Scenario 4 means that at EU level, job losses are less important, leading to a higher final consumption contribution (0.1% of GDP).

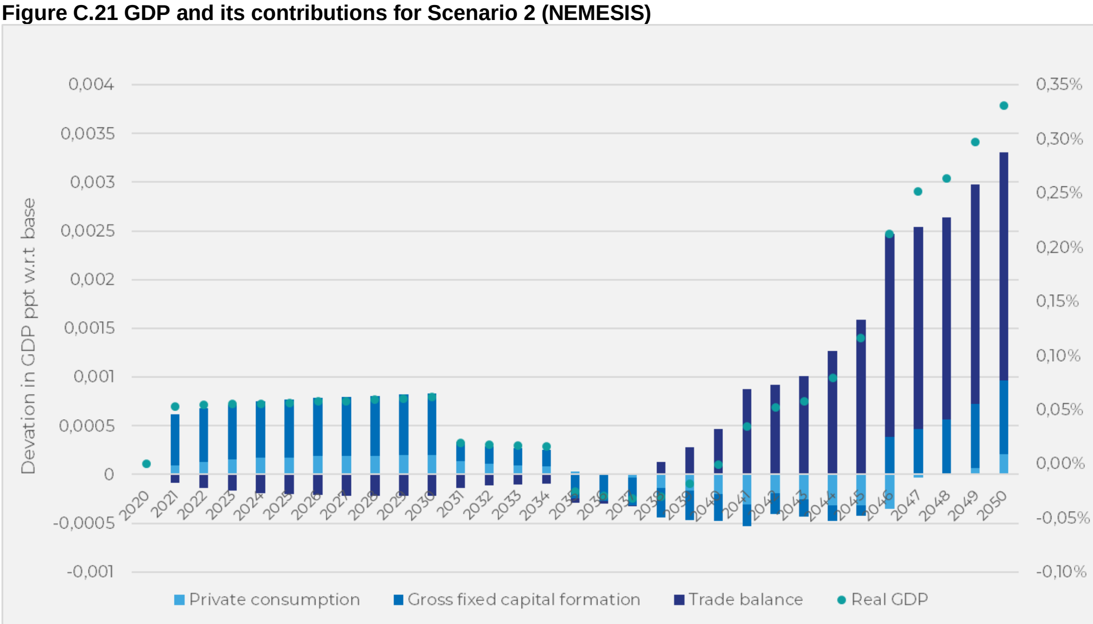
Figure C.20 GDP and its contributions for Scenario 4 (NEMESIS)



GDP % deviation with respect to baseline

Source: SEURECO.

Figure C.21 GDP and its contributions for Scenario 2 (NEMESIS)



GDP ppt % deviation with respect to baseline.

Source: SEURECO.

Regarding sectoral Employment (Table C.56), the late arrival of CAD level 5 on the market (2045) strongly limits the impact on employment in land transport services, as job losses are of -2.82% compared to Baseline.

Table C.56 Employment in some sectors for Scenario 4 (NEMESIS)

	2030	2040	2050
Electrical Equipment (Incl. Electronics)	0.02% (0.4)	0.01% (0.2)	0.25% (4.8)
Transports Equipment	0.10% (3.3)	0.02% (0.7)	0.57% (18.2)
Construction	0.05% (6.8)	0.03% (3.1)	0.07% (6.8)

	2030	2040	2050
Land Transports	0.38% (20.3)	0.16% (7.9)	-2.82% (-130.5)
Other market Services	0.02% (7.2)	0.01% (5.6)	0.02% (8.7)

% deviation with respect to baseline, Employment deviation in level (thousands).

Source: SEURECO.

Advantages of forerunners versus followers

Traditionally, forerunners have always an advantage over their followers. Leaders on the market can introduce CAD more rapidly in the countries and the spread all over the economy is facilitated. We will show by taking two examples that this is indeed the case.

In Scenario 1 and 2, Italy is assumed a forerunner country, but Spain is not.

As one can see in the Table C.57 , in Scenario 1 GDP gains are higher in Spain (+0.98% in 2050 compared to baseline) than in Italy (+0.54%). However, the impact on job losses in land transport services is also much more important (-68.5% in Spain, instead of -22.6% in Italy).

The same applies for Scenario 2, even if the differences are less important due to the higher regulations imposed. GDP is rising by +0.42% in Spain, and is slightly lower in Italy (0.34%), but once again, the quick development of CAD in Spain penalise employment in land transport services with a loss of 11.6% of jobs compared to -8.7% in Italy.

Table C.57 Comparing results for Italy and Spain in Scenario 1 & 2 (NEMESIS)

	GDP		Employment in Land transports	
	Italy	**Spain**	**Italy**	**Spain**
Scenario 1	0.54%	0.98%	-22.59%	-68.47%
Scenario 2	0.34%	0.42%	-8.66%	-11.57%

% deviation with respect to baseline in 2050.
Source: SEURECO.

In Scenario 3 and 4, Germany is among the forerunners while France is not. We can note that in Scenario 3 GDP gains in 2050 are much higher in Germany (+1.03%) than in France (+0.33%). But the stronger development of CAD vehicles implies more job losses in land transport for the forerunner country (-18.9%) than for France (-11.8%). The same applies for Scenario 4 where Germany faces GDP gains of +0.39% with respect to the baseline, while GDP remains almost at the same level in France. Once again job losses in the Land Transport sector are much higher in Germany (-14%) than in France where it even slightly grows (0.14%) due to the very late arrival of CAD level 5 vehicles in the market.

Table C.58 Comparing results for Germany and France in Scenario 3 & 4 (NEMESIS)

	GDP		Employment in transports	
	Germany	**France**	**Germany**	**France**
Scenario 3	1.03%	0.33%	-18.9%	-11.8%
Scenario 4	0.39%	0.02%	-13.94%	0.14%

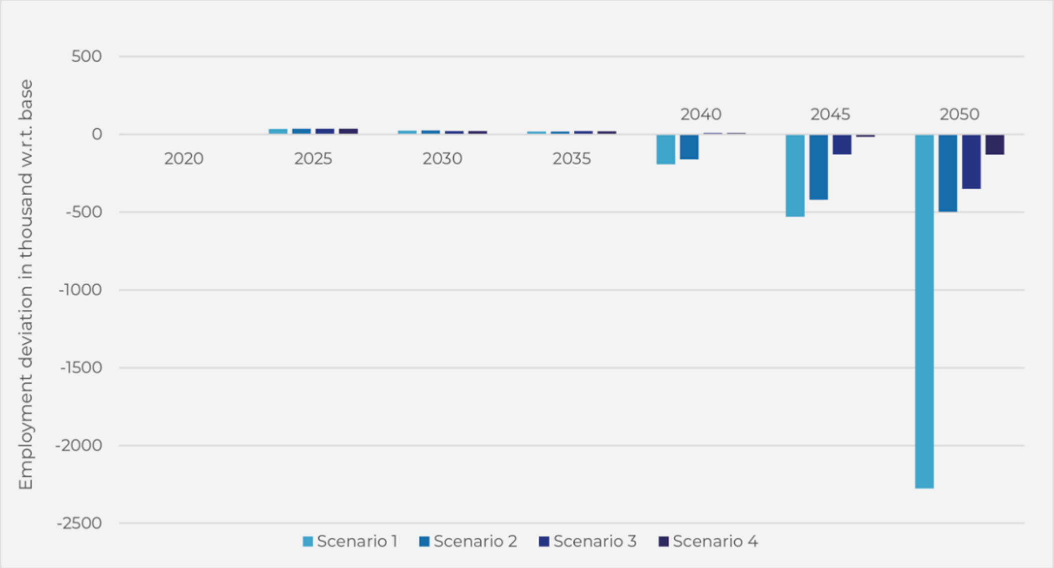
% deviation with respect to baseline in 2050.
Source: SEURECO.

Scenario comparison in the NEMESIS model

Due to their settings, the four scenarios representing different possible pathways for Connected and Automated Driving lead to very contrasted employment impacts on European economies. Not surprisingly the most affected sector impacted by CAD development and spreading in the economy, particularly regarding Level 5, is the sector Land Transport Services.

As one can see in Figure C.22 , the more CAD level 5 spreads in European economies, the more the employment impact on the sector is important. In the first scenario where level 5 vehicles arrive early in the market (2035) and where no regulations are imposed, the impact on employment in this sector is particularly important in 2050 with 2,276 thousand job losses. On the opposite, in Scenario 4, where level 5 vehicles arrive later on the market (2045), the diffusion of CAD level 5 in the overall economy is not at its maturity, and so job losses are very low (-130.5 thousand).

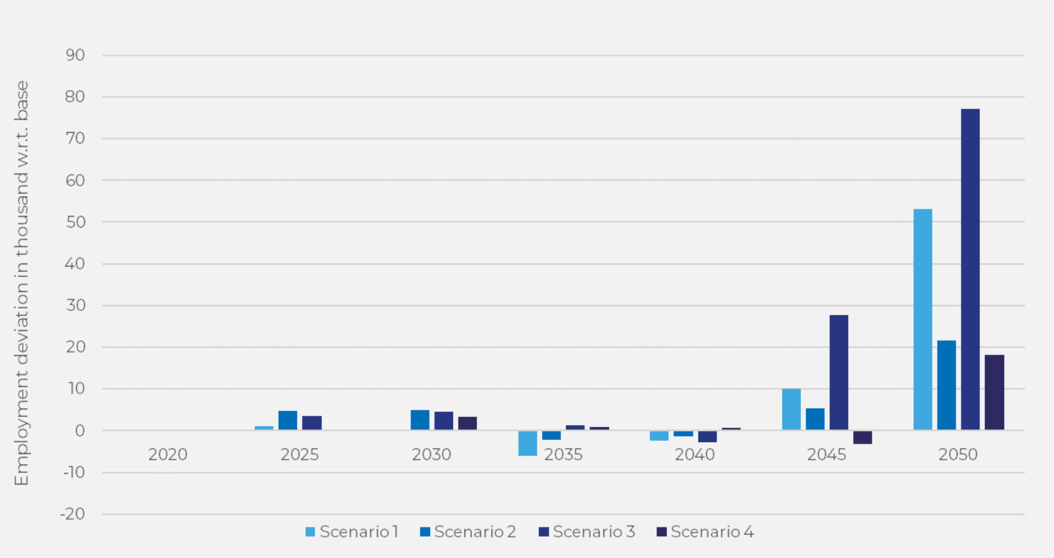
Figure C.22 EU Employment Deviation for the Land Transport Sector (NEMESIS)



Employment in thousand jobs deviation with respect to baseline.
Source: SEURECO.

Regarding the other sectors impacted by CAD, the Transport Equipment sector takes advantage (Figure C.23). In the two first scenarios, where private mobility is considered, households will have to buy new cars for replacing old ones, and the transport services must invest to get to the higher CAD level leading to an employment increase (+53.2 thousand and +21.7 thousand with respect to baseline). In Scenario 3 and 4, households consume less cars, but their demand of transport services increases, leading the transport services to invest in new CAD levels. This drives employment gains to +77 and +18.2 thousand jobs, respectively.

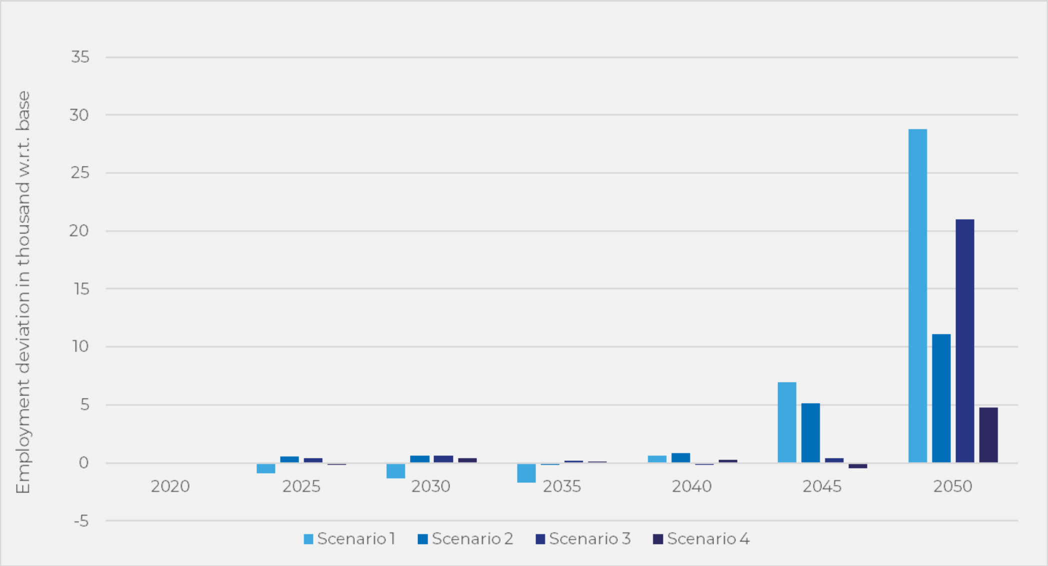
Figure C.23 EU employment Deviation in Transport Equipment (NEMESIS)



Employment in thousand jobs deviation with respect to baseline.
Source: SEURECO.

Following the increasing demand addressed to the transport equipment sector, the need for electric and electronic goods rise (Figure C.24). Consequently, the employment impact on this sector is positive and follow the same pattern as the transport equipment sector.

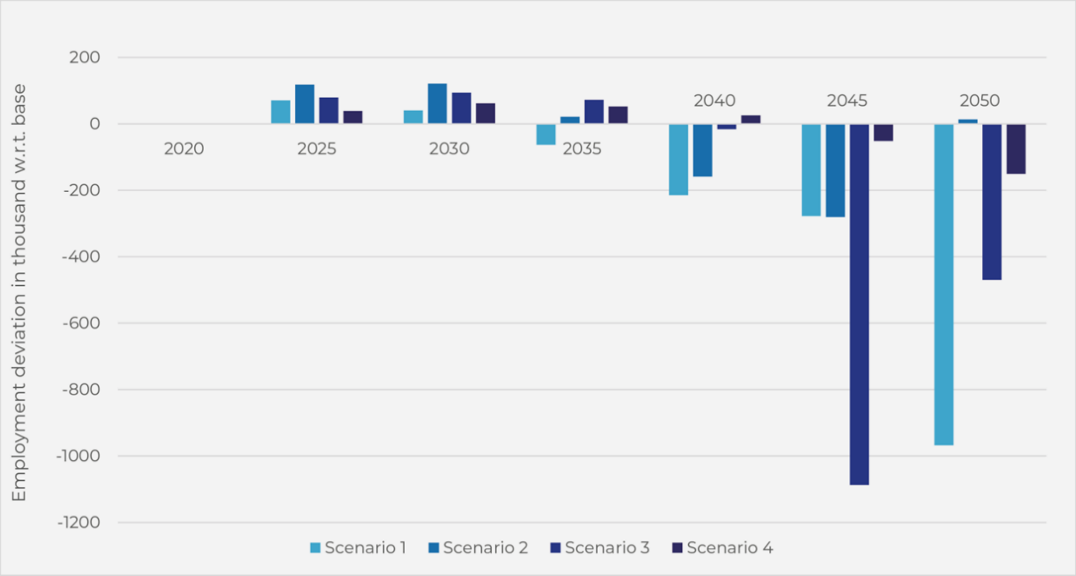
Figure C.24 EU Employment Deviation in Electrical Equipment (NEMESIS)



Employment in thousand jobs deviation with respect to baseline.
Source: SEURECO.

At the macroeconomic level, even though some sectors take advantage of the CAD development, the total employment effect remains negative. The strong decrease on employment in the land transport services sectors is not compensated by the increase in the other sectors except in the second scenario where total employment is near to zero. In the case where CAD arrives early on the market without restrictive regulation (Scenario 1), the total employment impact is of 967 thousand job losses.

Figure C.25 Total European Employment (NEMESIS)



Employment in thousand jobs deviation with respect to baseline.

Source: SEURECO.

Comparison of employment results in ASTRA and NEMESIS

In this section, we present a detailed comparison of CAD impacts on employment by the two economic models ASTRA and NEMESIS. The comparison considers two aspects: (i) sectoral employment including manufacturing sectors, construction and the transport service sector and (ii) total employment based on second-round effects induced by overall economic circumstances.

First, the model approaches are briefly compared before the employment effects of CAD and their driving factors are explained in detail.

Comparison of Modelling Approaches

Both models allow a detailed sectoral simulation for the EU economy including consumption, investment and external trade with other world regions. In both models, employment is based on the demand side assessment of employment.

Regarding the integration of CAD, both models follow the same approach. The Scenario Model data of transport expenditures by firms and households is linked to the same economic indicators: Expenditures for firms (bus, commercial cars, trucks) and infrastructure expenditures are allocated as investment. Expenditures of households, including the purchase of cars as well as the expenditures for different transport services, are allocated to the respective consumption categories.

The Scenario Model outputs and the transfer of infrastructure investments allows the impact assessment based on a common ground. Nevertheless, the model results arise from a combination of exogenous interventions and endogenous model reactions. Hence, the models do not react identically to exogenous specifications.

One difference between the models is the number and thus the allocation of economic sectors. This results in slight deviations of economic indicators, e.g. employment, at the sectoral level. While ASTRA has 25 sectors, NEMESIS includes 30 sectors. The CAD-relevant sectors (Vehicles, Electronics, Computers, Communications, and Construction) largely match for both models. Only for the sector Communication, there are some slight differences in the assignment of subsectors as shown in table C.1. However, by comparing percentage results with respect to baseline, these small differences in allocation do not matter.

Employment of mobility services is modelled by means of the Mobility Service Model within ASTRA that allows a breakdown into job categories. This level of detail is not given by the NEMESIS model. The comparison of transport services between ASTRA and NEMESIS is performed by comparing the Inland Service sector in total.

The Component Model within ASTRA proves to be a suitable instrument for investigating the effects of CAD on sectoral employment. The disaggregation of components and the assignment to the specific sectors will result in a shift of sectoral employment in favour of sectors producing future-oriented CAD components. In contrast, NEMESIS attributes these developments to the Vehicles sector, whereby the positive impact of CAD on this sector will be higher than in ASTRA.

In a system model such as ASTRA and NEMESIS many different aspects of the economy are modelled in an integrative approach. Complex, interacting systems of equations form the core of both economic models. An integrative approach sometimes makes simplified assumptions and estimates necessary. These simplifications differ in both models and prevent an indicator from matching exactly at a certain point in time. Nevertheless, an important quality measure of the modelling is that, in addition to the magnitude, above all the development over time and future trends of economic indicators are plausibly mapped.

The following section compares the results of sectoral and total employment.

Comparison of employment results

ASTRA and NEMESIS agree on the finding that the rollout of CAD decreases total employment. Total employment develops negatively compared to baseline due to job losses in transport services that cannot be compensated by employment gains in manufacturing sectors and a stimulating economic environment. When CAD arrives early and unrestricted on the market, the negative impact on total employment is more severe.

Table C.59 compares total employment assessed in both models.

Table C.59 Total employment of EU27, all scenarios

	ASTRA						NEMESIS					
	2025		2035		2050		2025		2035		2050	
Base	197,201		193,374		188,866		207,838		211,351		210,587	
Sc. 1	-35	-0.02%	116	0.06%	-649	-0.34%	70	0.03%	-63	-0.03%	-967	-0.46%
Sc. 2	20	0.01%	102	0.05%	-844	-0.45%	118	0.06%	21	0.01%	13	0.01%
Sc. 3	-20	-0.01%	21	0.01%	-334	-0.18%	79	0.04%	72	0.03%	-470	-0.22%
Sc. 4	-27	-0.01%	-40	-0.02%	-54	-0.03%	39	0.02%	52	0.02%	-150	-0.07%

Baseline in thousand jobs. Scenario results show deviation from Baseline in thousand jobs and % change.
Source: M-Five and SEURECO.

In scenario 1, the impact of CAD on total employment is fairly similar in both models. ASTRA (-0.34%) computes a slightly lower total job loss in 2050 than NEMESIS (-0.46%) due to a slightly higher economic performance.

Scenario 2 is characterised by an early availability of automated vehicles, but higher regulations that limit the penetration of CAD into the market and hence the benefits of investment in CAD. Almost all macroeconomic variables show smaller figures than in Scenario 1. These macroeconomic developments lead to a greater decrease in total employment in the ASTRA model (-0.45%). In contrast, NEMESIS shows an unchanged EU27 total employment compared to the baseline. This difference in results is driven by the developments in transport service employment that are explained below.

Scenario 3 is characterized by a later CAD uptake as well as a focus on shared mobility. It shows slower CAD developments. Impacts unfold much later than in Scenario 1 and 2. ASTRA (-0.18%) and NEMESIS (-0.22%) both calculate an intermediate decrease in total employment.

A very late CAD uptake (scenario 4) has only limited second-round effects until the end of the study horizon 2050. Total employment therefore changes only slightly compared to the baseline in both models.

Table C.60 shows the underlying GDP development that drives total employment via second-round effects in both models. The transition to CAD accelerates growth through a boost to fleet renewals, higher value vehicles and infrastructure and facility investments. This affects the manufacturing and transport service sectors, but also increases aggregate demand in the economy as a whole, which indirectly drives employment.

Table C.60 GDP of EU27, all scenarios

	ASTRA						NEMESIS					
	2025		2035		2050		2025		2035		2050	
Base	12,987,367		14,942,739		18,468,934		13,218,155		15,186,438		18,812,244	
Sc. 1	14,682	0.11%	38,277	0.26%	197,934	1.07%	3,704	0.03%	-10,521	-0.07%	169,488	0.89%
Sc. 2	17,616	0.14%	40,436	0.27%	79,942	0.43%	8,371	0.06%	-3,384	-0.02%	65,514	0.35%
Sc. 3	3,892	0.03%	33,092	0.22%	91,624	0.50%	6,246	0.05%	3,316	0.02%	184,726	0.92%
Sc. 4	4,069	0.03%	23,005	0.15%	49,072	0.27%	-408	-0.01%	1423	0.01%	70,218	0.37%

Baseline in Mio. €2005. Scenario results show deviation from Baseline in Mio. €2005 and % change.
Source: M-Five and SEURECO.

Both economic models show similar aggregated effects of GDP, but respond differently to the respective economic drivers. ASTRA responds stronger on the productivity effect of investments into CAD. Developments in NEMESIS are driven by a transport cost decrease of CAD improving competitiveness and exports.

In the following, the effects on sectoral employment are summarized.

In both models, manufacturing employment is gradually declining over time in almost all sectors. However, CAD-relevant sectors are dampening this trend, as employment increases with CAD becoming more important. A strong CAD ramp-up has a positive effect on sectors producing autonomous vehicles and CAD-components.

The Vehicles sector as well as the Electronics sector take particular advantages. These are most pronounced in the two first scenarios, where individual mobility is considered and households and firms buy new vehicles to replace old ones. ASTRA shows a relatively higher job gain in the Electronics sector than in the Vehicles sector, while it is the other way around in NEMESIS. The disaggregation of components and the assignment to the specific sectors in ASTRA results in a shift of sectoral employment in favour of sectors producing future-oriented CAD components such as Electronics. NEMESIS attributes these developments to the Vehicles sector, whereby the positive impact of CAD on this sector is higher than in ASTRA.

A positive impact of CAD happens also in other CAD-relevant manufacturing sectors such as Communication as well as in the Construction sector, albeit to a lesser extent than in the sectors Vehicles and Electronics.

Both models see transport services as severely negatively affected by CAD. The development over time and a comparison between scenarios show that the more Level 5 vehicles penetrate the economy, the more losses the Inland Transport sector records.

In scenario 1 with early and unregulated CAD uptake, the decrease in employment in transport services is especially strong. In NEMESIS job losses account for even -50% compared to baseline in 2050, corresponding to 2,276 thousand jobs. In ASTRA the number is a little less (-14.15%), but still costs a considerable number of jobs (-1,085 thousand jobs). Reason is that ASTRA does not include endogenous changes of modal split in the macroeconomic model. In contrast, NEMESIS shows a modal shift, as the extensive use of private cars substitutes public services considerably.

In scenario 2, NEMESIS shows a less negative impact (-10.75%) than ASTRA (-15.64%) on transport service employment. Reason is that ASTRA includes a sophisticated freight model and hence emphasizes the developments in the freight sector, that are assumed in scenario 2, more strongly.

A focus on shared mobility (scenario 3) results in less employment losses in transport services than in the other scenarios. This effect is a bit stronger in NEMESIS (-7.55%) than in ASTRA (-11.13%). NEMESIS expects higher employment needs to meet the demand for mobility services.

Scenario 4 shows a limited impact on transport service employment. Below, a comparison is provided in more detail for each scenario.

Scenario 1

In scenario 1, a relatively early arrival of CAD on the market and a low regulation entail a quick and large deployment of CAD in the EU. Infrastructure investments and replacement of cars and trucks drive macroeconomic results.

The impact of CAD on total employment is fairly similar in both models. Total employment decreases by 0.44% with respect to baseline in 2050 in NEMESIS. It falls in a comparable order of magnitude in ASTRA (-0.34%). The slightly lower total job losses in ASTRA are a result of a somewhat higher economic performance. In ASTRA, GDP starts to rise much earlier driven by a stronger positive impact of investments. NEMESIS shows a less positive impact of CAD on investment, but a stronger positive change of exports than ASTRA.

In NEMESIS, the development of CAD leads to relatively high productivity gains with respect to the rest of the World that explains the strong positive contribution of exports. But this point needs to be put in perspective as we do not make any assumptions regarding the development of CAD in the countries outside the EU (except United-Kingdom, Norway and Switzerland). If we suppose that other countries follow more or less the same pace, this positive contribution is maybe lower.

Final households' consumption in the NEMESIS model is not much affected by the decrease of employment, because of the slight price decrease following productivity gains. In ASTRA, final consumption even increases compared to baseline due to the rise in demand for private cars and other products based on an increasing economic performance.

Table C.61 Main macroeconomic results for Scenario 1

	ASTRA			NEMESIS		
Scenario 1	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
GDP	0.21%	0.35%	1.07%	0.01%	-0.02%	0.89%
Final Consumption	0.35%	0.75%	1.30%	0.04%	-0.05%	-0.03%
Investment	1.14%	3.54%	5.13%	0.22%	-0.15%	0.83%
Exports	0.07%	0.08%	0.25%	-0.15%	0.07%	1.93%
Imports	0.09%	0.13%	0.33%	0.04%	-0.06%	0.04%
Total Employment	0.03%	-0.04%	-0.34%	0.02%	-0.10%	-0.44%
	(64)	(-76)	(-649)	(48)	(-258)	(-967)

%-Deviation to baseline, plus total employment deviation in level (thousand jobs, in brackets).
Source: M-Five and SEURECO.

Note, that the NEMESIS model shows an investment and hence GDP in 2040 that is lower than in baseline. The reason for this is the delayed introduction of CAD in the baseline, which results in higher infrastructure investments in the 2040s, when infrastructure in the scenarios is already set up. In contrast, ASTRA includes additional impulses on investment from transport demand and hence shows a continuously higher investment compared to baseline.

In both models, manufacturing sectors see their employment increase, benefiting from the development of and investment in CAD. This holds especially for Vehicles and for Electronics. ASTRA shows a relatively higher job gain in the Electronics sector than in the Vehicles sector, while it is the other way around in NEMESIS. Here, ASTRA benefits from a disaggregation of components and the assignment of individual vehicle components to the specific sectors, whereby Electronic gains of importance with the uptake of CAD relative to the Vehicle sector. NEMESIS attributes these developments to the Vehicles sector, whereby the positive impact of CAD on this sector is higher than in ASTRA.

The negative impact on employment in transport services is considerably high in Scenario 1. The NEMESIS model computes a loss of almost 50%, equivalent to 2,276 thousand jobs, compared to baseline 2050. ASTRA shows a decrease of 14.15%, equivalent to 1,085 thousand jobs. In NEMESIS, transport service employment is driven by developments of the fleet. In Scenario 1, the extensive use of private cars substitutes public services. NEMESIS includes the possibility of a model shift in the modelling of consumption. As a result, employment in transport services is falling sharply due to the increase in the demand for private cars and purchasing expenditures creating an additional modal shift effect. In contrast, there are no changes of modal split in the macroeconomic model of ASTRA. Here, transport expenditures are the sole drivers of consumption, investment and consequently sectoral employment.

Table C.62 Employment in relevant sectors for Scenario 1

	ASTRA			NEMESIS		
Scenario 1	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Vehicles	-0.09%	0.29%	0.96%	0.00%	-0.07%	1.67%
	(-3,675)	(12,134)	(40,308)	(+160)	(-2,350)	(53,180)
Electronics	0.50%	0.10%	1.78%	-0.08%	0.03%	1.49%
	(9,030)	(1,772)	(32,856)	(-1,330)	(590)	(28,790)

Computers	0.28%	0.37%	1.16%	-0.05%	0.01%	1.39%
	(756)	(965)	(3,005)	(-590)	(220)	(21,730)
Communication	0.07%	0.18%	0.28%	-0.01%	-0.01%	0.50%
	(1,926)	(4,874)	(7,297)	(-90)	(-500)	(37,780)
Construction	0.08%	0.01%	0.63%	0.10%	-0.06%	0.69%
	(11,161)	(1,522)	(84,933)	(13,640)	(-6,950)	(64,310)
Inland Transport Services	-0.94%	-2.99%	-14.15%	0.60%	-3.80%	-49.19%
	(-72,780)	(-228,822)	(-1,084,677)	(23,090)	(-191,640)	(-2,276,180)

% deviation to baseline, total deviation in jobs (in brackets).
Source: M-Five and SEURECO.

Scenario 2

Scenario 2 is also characterised by an early availability of automated vehicles. However, higher regulations will limit the penetration of CAD into the market and hence the benefits of investment in CAD. Almost all macroeconomic variables show smaller figures than in Scenario 1.

These macroeconomic developments lead to a greater decrease in total employment in the ASTRA model (-0.45%). In contrast, NEMESIS shows an almost unchanged EU27 total employment compared to the baseline. This difference in results is driven by the developments in transport service employment that are explained below.

Table C.63 Main macroeconomic results for Scenario 2

	ASTRA			NEMESIS		
Scenario 2	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
GDP	0.23%	0.26%	0.43%	0.06%	0.00%	0.33%
Final Consumption	0.35%	-0.08%	-0.69%	0.04%	-0.04%	0.04%
Investment	1.20%	0.56%	3.40%	0.28%	-0.12%	0.33%
Exports	0.08%	0.09%	0.09%	-0.01%	0.09%	0.68%
Imports	0.09%	0.12%	0.08%	0.06%	-0.05%	0.05%
Total Employment	0.02%	-0.08%	-0.45%	0.06%	-0.07%	0.01%
	(47)	(-151)	(-844)	(121)	(-159)	(13)

%-Deviation to baseline, plus total employment deviation in level (thousand jobs, in brackets).
Source: M-Five and SEURECO.

The impact of scenario 2 on the manufacturing sectors is similar in both models. It is positive, but less pronounced than in scenario 1. The same mechanisms operate that have already been explained above.[45]

For transport services, NEMESIS shows a less negative impact (-10.75%) than ASTRA (-15.64%). Reason is that ASTRA includes a sophisticated freight model and hence emphasizes the developments in the freight sector, that are assumed in scenario 2, more strongly. After a growth in demand for employment driven by increased traffic demand, freight transport services experience a sharp decline in employment as vehicle fleets are rapidly transformed with new automated and cost-saving vehicles.

Table C.64 Employment in relevant sectors for Scenario 2

	ASTRA			NEMESIS		
Scenario 2	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**

45 The value for communication in the year 2050 in ASTRA is an outlier. In previous years, the results of the sector behave similarly to NEMESIS' results.

Vehicles	-0.05% (-2,271)	0.14% (5,726)	0.85% (35,795)	0.15% (4,890)	-0.04% (-1,390)	0.68% (21,720)
Electronics	0.52% (9,499)	-0.24% (-4,451)	1.48% (27,380)	0.04% (640)	0.04% (830)	0.57% (11,080)
Computers	0.31% (848)	0.22% (574)	0.86% (2,239)	0.08% (1,100)	0.02% (340)	0.54% (8,530)
Communication	0.09% (2,466)	0.16% (4,218)	-0.38% (-10,047)	0.02% (1,280)	0.00% (-10)	0.20% (14,600)
Construction	0.09% (12,528)	0.00% (-435)	0.43% (57,286)	0.15% (19,140)	-0.03% (-3,320)	0.31% (28,690)
Inland Transport Services	-1.73% (-133,010)	-3.93% (-300,509)	-15.64% (-1,199,056)	0.47% (25,270)	-3.17% (-159,880)	-10.75% (-497,520)

% deviation to baseline, total deviation in jobs (in brackets).
Source: M-Five and SEURECO.

Scenario 3

Scenario 3 is characterized by a later CAD uptake as well as a focus on shared mobility. Since the mass market entry of CAD occurs later than in previous scenarios and fewer countries are classified as forerunners, i.e. large countries such as France are followers, Scenario 3 shows slower CAD developments. Impacts unfold much later than in Scenario 1 and 2.

The scenario shows very similar results of the two models for total employment (-0.18%, -0.22%). Again, these results are driven by different mechanisms. ASTRA sees a greater importance of investments and final consumption. NEMESIS, on the other hand, shows a stronger increase in exports due to relative productivity advantages compared to the rest of the world. This pattern extends across all scenarios. However, in order to meet the increase in demand for ride-sharing, NEMESIS sees a higher relative investment requirement (compared to other scenarios) than ASTRA.

Table C.65 Main macroeconomic results for Scenario 3

	ASTRA			NEMESIS		
Scenario 3	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
GDP	0.13%	0.24%	0.50%	0.05%	-0.04%	0.86%
Final Consumption	0.28%	0.59%	1.11%	0.02%	-0.01%	0.34%
Investment	0.92%	0.29%	3.87%	0.24%	-0.14%	1.31%
Exports	0.04%	0.07%	0.08%	0.00%	-0.01%	1.13%
Imports	0.05%	0.10%	-0.02%	0.05%	-0.02%	0.11%
Total Employment	-0.02% (-47)	0.06% (120)	-0.18% (-334)	0.04% (79)	-0.01% (-16)	-0.22% (-470)

%-Deviation to baseline, plus total employment deviation in level (thousand jobs, in brackets).
Source: M-Five and SEURECO.

For employment in manufacturing sectors, ASTRA and NEMESIS show different results in magnitude. In ASTRA, the employment gains compared to baseline are not as high as in the previous scenarios due to a shift in demand from vehicles to transport services. NEMESIS shows a more positive view on sectoral employment that is stimulated by higher economic growth.

As scenario 3 emphasises shared mobility, employment in transport services is less negatively impacted than in other scenarios. This result holds both in ASTRA (-11.13%) as well as in NEMESIS (-7.55%).

Table C.66 Employment in relevant sectors for Scenario 3

	ASTRA			NEMESIS		
Scenario 3	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Vehicles	0.02%	0.04%	0.22%	0.14%	-0.09%	2.42%
	(958)	(1,767)	(9,300)	(4,540)	(-2,830)	(77,040)
Electronics	0.28%	-0.03%	0.45%	0.02%	-0.01%	1.09%
	(5,107)	(-624)	(8,334)	(610)	(-210)	(20,980)
Computers	0.06%	0.24%	-0.12%	0.04%	-0.03%	0.78%
	(160)	(644)	(-305)	(960)	(-420)	(12,220)
Communication	0.07%	0.14%	-0.21%	0.02%	-0.01%	-0.45%
	(1,995)	(3,676)	(-5,633)	(920)	(-370)	(-33,950)
Construction	0.09%	0.02%	-0.08%	0.11%	-0.03%	0.80%
	(12,213)	(3,283)	(-10,845)	(14,130)	(-3,770)	(74,210)
Inland Transport Services	-2.51%	-0.61%	-11.13%	0.64%	0.16%	-7.55%
	(-193,313)	(-46,629)	(-853,172)	(20,350)	(7,840)	(-349,530)

% deviation to baseline, total deviation in jobs (in brackets).
Source: M-Five and SEURECO.

Scenario 4

In scenario 4, level 5 vehicle enter the market later than in other scenarios. The impact of CAD on employment is limited. Total employment decreases by 0.03%, respectively 0.07%, compared to baseline 2050 in the two models. Effects on all macroeconomic variables are less pronounced.

Table C.67 Main macroeconomic results for Scenario 4

	ASTRA			NEMESIS		
Scenario 4	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
GDP	0.06%	0.21%	0.27%	0.04%	0.00%	0.31%
Final Consumption	0.24%	0.55%	0.23%	0.01%	0.00%	0.18%
Investment	0.81%	0.62%	0.58%	0.19%	0.03%	0.36%
Exports	0.02%	0.07%	0.07%	-0.01%	0.00%	0.36%
Imports	0.01%	0.08%	0.06%	0.03%	0.01%	0.00%
Total Employment	-0.04%	0.01%	-0.03%	0.03%	0.01%	-0.07%
	(-84)	(20)	(-54)	(71)	(28)	(-187)

%-Deviation to baseline, plus total employment deviation in level (thousand jobs, in brackets).
Source: M-Five and SEURECO.

The late arrival of autonomous vehicles in scenario 4 strongly limits the impact on sectoral employment. While NEMESIS shows a slight increase in manufacturing employment, it is almost the same in ASTRA with respect to baseline. Similarly, job losses in transport services are smaller than in other scenarios.

Table C.68 Employment in relevant sectors for Scenario 4

	ASTRA			NEMESIS		
Scenario 4	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**

Vehicles	0.02%	-0.01%	0.13%	0.10%	0.02%	0.57%
	(990)	(-526)	(5,546)	(3,300)	(680)	(18,190)
Electronics	0.08%	0.10%	-0.08%	0.02%	0.01%	0.25%
	(1,423)	(1,829)	(-1,478)	(390)	(240)	(4,750)
Computers	0.05%	0.12%	-0.09%	0.04%	0.01%	0.08%
	(130)	(318)	(-225)	(550)	(280)	(1,200)
Communication	0.05%	0.09%	-0.35%	0.01%	0.00%	0.14%
	(1,361)	(2,456)	(-9,071)	(430)	(280)	(10,450)
Construction	0.04%	0.08%	0.00%	0.05%	0.03%	0.07%
	(5,695)	(11,389)	(-550)	(6,770)	(3,130)	(6,810)
Inland Transport	-2.51%	-1.77%	-5.13%	0.64%	0.16%	-2.82%
Services	(-193,458)	(-135,705)	(-393,532)	(20,260)	(7,860)	(-130,450)

% deviation to baseline, total deviation in jobs (in brackets).
Source: M-Five and SEURECO.

Annex D – Literature review and sources

Literature review

Connected and Automated Driving state of play and outlook

Through the initial literature research, we identified that relevant information (qualitative and quantitative elements) are available for a number of focus areas of this study as summarised below. The full list of analysed literature references is presented in Table D.7 towards the end of Annex D. In this chapter, we will refer to literature listed in this table by noting the number of the source in squared brackets:

- Research and Innovation strategy for CAT, for the various transport modes (Road, Railway and Waterborne Transport) - Policy Objectives and Challenges, State of the Art, hurdles and opportunities, roadmaps and plans, programs and projects [1];
- Implications of technologies and automation affecting the future of work to the year 2040 in the transport industry at a global level [3];
- Current CAD status in several EU Member States along with listing several thematic areas on CAD. With focus on EU and international initiatives [4];
- Impact assessment framework for classifying automation implementations [6];
- Innovation status (2018) regarding patent filing in the automotive sector; analysis of current trends in patenting behaviour as an indicator on the technologies that are evolving -insight on areas of SDV technology Innovation [16];
- External competitiveness of the EU automotive sector to 2030 and beyond – a comparative analysis of the EU automotive sector in relation to China, India, Japan, South Korea markets [18];
- Future scenarios on skills and competences required by the Transport sector in the short, mid and long-term [20],[86];
- Roadmap and action plan for automation in road transport for years 2016-2020 are providing in a comprehensive manner, information relevant to the preparation for automated driving and its possibilities in Finland and in Europe [24];
- Development of systemic and holistic studies of impacts of self-driving vehicles. Focus is on system-level impacts of self-driving vehicles on the transportation system; addressing also wider societal impacts [17];
- Future workforce demands in the CAV space, analysing job postings for a broad set of occupations that may be involved in the design, manufacture, and infrastructure development included in the CAV product cycle in the US [23];
- Evolution of employment in EU-28 selected economic sectors 2008-2017 - economy, employment and skills;
- Occupational profiles for specific transport-related sectors for EU-28 in 2014:
  - relative wage position for specific transport-related sectors in EU Member States in 2014;
  - task profile of drivers and mobile plant operators [2].
- Unsatisfied demand and expected demand growth for drivers in freight and passenger employment:
  - Working conditions;
  - Age of drivers;
  - The population of drivers employed by gender and age to detect potential gaps;
  - The percentage of apprentices in the company;
  - The ratio of native vs. foreigner drivers employed; [6]

- The impact of automated transport on the role, operations and costs of road operators and authorities in Finland, describing, among others, the automated driving related legal frameworks and the strategies of regulatory authorities globally, and especially in Europe [8];
- Innovation data in the EU auto industry data on the production, registration, international trade and taxation of motor vehicles [9].

A summary of the most relevant Information from the publications referenced in table are presented in the sections below.

Current state of Connected and Automated Driving

This section summarises some of the most interesting findings relevant to the expectations for the deployment of CAD and its expected impacts as identified in the literature sources cited in Table D.7. The reference to the number of the relevant literature piece can be found for each of the presented findings.

Connected and Automated Driving (CAD) is a major technology area where significant technology advancements occur; as such is shaping our future mobility and influencing our life [14]. CAD is one of the transformative powers for the automotive industry which is also embracing the upcoming digital revolution, environmental challenges and societal changes [18], [26].

A holistic consideration of the CAD state of the art needs to take into account technology enablers and at the same time to consider the social, economic, human factors and legal aspects. CAD touches upon a number of important societal challenges of road transport, namely road safety, traffic congestion, energy efficiency, decarbonisation, social inclusiveness, and more [1], [30]. Ultimately, CAD aligns with the 2050 Vision Zero of no road fatalities on European roads by 2050 with the potential of saving hundred thousand of lives by increasing the safety performance of road transport until then and consequently avoiding socio-economic costs of trillion of euros [31],[37],[38].

The timeline of CAD

Technological progress (compact electronics etc.), consumer demand, improved ICT connectivity, the uptake of the sharing economy and emissions & safety regulations can be considered some key industrial drivers enabling the development and evolution of CAD [32,34,35]. Many vehicles are already connected with cellular technologies and all new cars are expected to be connected to the internet by 2022 [26], [27]. Self-driving vehicles are already a reality in proof-of-concept testing around the world. However, many technical challenges remain and need to be solved in order for the vehicle to fully ‘sense’ its surrounding environment and take the right decisions [26], [32]. There is still a way ahead of us before fully automated (Level 5) vehicles can become available.

Vehicles assisting the driver through supporting systems, like Advanced Driver Assistance Systems (ADAS) are designed to offer drivers comfort, improve safety and minimise driver errors. Driving control is categorised by one of six levels of automation. The levels range from zero to five: zero requiring complete human driving interaction and five being full autonomous navigation without human participation (SAE 2016-2018) [33]. Vehicles incorporating level 1 and 2 technologies like cruise control, hazard warning and automated parallel parking are already available in the European market [51].

According to most experts, automated vehicles are currently between SAE levels 2 and 3, although public perception sees them often much further in development [36]. As automotive manufacturers are moving towards level 4 and 5 automation based on successfully deployed level 2 and 3 ADAS automation, they still have to face the technological challenges posed by the transition from level 3 to 4 where the functioning of the existing technology and the cooperation between relevant systems still needs to be perfected. This progression is not a linear one but rather represents a large step in system reliability since classic rule-based ADAS functions reach their limits with level 3 requirements.

Automated vehicles at levels 3 and 4, i.e. capable to operate under specific conditions are currently being tested [4] and market introduction is on the way, with level 3 focussing mainly on an automated highway pilot and level 4 on applications such as automated valet parking and level 4 robotaxis[46] [73].

There are significant discrepancies on when fully automated vehicles will become available in the market [42]. According to ERTICO the next Generation Connected Level 4 mobility can be achieved by 2025 and driverless mobility, commercially deployed by 2030 [39]. ERTRAC's roadmap shows that passenger cars could be highly automated (Level 4) by 2025 looking at full automation (Level 5) towards 2030 [4]. However, level 5 autonomous driving will be difficult to achieve with current technologies confirming the need for physical and digital infrastructure, including Vehicle-to Infrastructure (V2I) connectivity, required infrastructure sensors and backbone communication networks [29].

Although expectations regarding the first introduction and further implementation of automated vehicles vary considerably [66], the consensus of the majority of industry is that full and unconditional automation, i.e. Level 5, is unlikely to be introduced before 2030 [73], [84]. This conflicts with earlier, more optimistic beliefs that full automation could be achieved already in the early 2020's and merely showcases the intricacies of CAD. In the following subsections a comparison is provided between the expectations for the advent of fully autonomous vehicles by vehicle manufacturers in 2016 and updated estimates as they currently stand.

Connected Automated Driving Industrial Status (2016)

In the recent years, vehicle manufacturers have created timelines in order to announce the release of their automated vehicles. Table D.1 presents a collation of noteworthy estimations extracted from press releases and announcements made by major companies in the field. Here, the technological advancements already introduced or realistically expected in 2016 are presented aside their predictions for future developments. As can be observed, the majority of predictions were announcing the introduction of fully autonomous vehicles by 2020-21 [50].

Table D.1 Estimated market introduction of CAD systems (2016)

Organization	Confirmed and expected product introduction (2016)	Predictions for introduction of fully-autonomous vehicles
Audi/VW	2016 – Piloted Driving	Available by 2021
BMW	2014 – traffic jam assist 2014 – automated parking	Available by 2021
Bosch	2017 – Integrated Highway Assist 2020 – Highway Pilot	Auto Pilot by 2025
Continental		Available by 2020
Daimler-Benz	2014 – Intelligent Drive	Available by 2020
Ford	2015 – fully assisted parking	To mass produce AV in 2021
Google	2015 – Driverless Pod prototype	Available by 2018
Honda		Available by 2020

46 A Robo-Taxi, also known as a Robo-Cab, a self-driving taxi or a driverless taxi is an autonomous car (**SAE Level 4** or 5) operated for an e-hailing (on-demand mobility) service.

Organization	Confirmed and expected product introduction (2016)	Predictions for introduction of fully-autonomous vehicles
Hyundai		Available by 2030
Mobile Eye	2016 – technology ready for OEMs	
Nissan	2016 – traffic jam pilot 2018 – multiple lane control	Available by 2020
Tesla	2015 – Lane Assist + ACC 2016 – highly autonomous	Self-driving 2020-2025
Toyota	Mid 2010s – highly autonomous	
Volvo	2015 – traffic jam assist 2017 – Drive Me FOT in Sweden	Zero Fatality cars by 2020

Source: Ching-Yao Chan, Advancements, prospects, and impacts of automated driving systems, California Partners for Advanced Transportation Technology Program (PATH), University of California at Berkeley, USA.

Connected Automated Driving Industrial Status (2019)

The current status (2019) on how car manufactures expect the next wave of automated vehicles introduction is highlighted in Table D.2 [74],[75].

Table D.2 Estimated market introduction of CAD systems (2019)

Organization	Updated predictions (2019)
BMW / Daimler-Benz	Nearly Fully Autonomous by Early 2020's; Level 4 cars should be released by 2024
Fiat-Chrysler	Self-driving technology on the road by 2021
Ford	True Self-Driving by 2021
General Motors	Self-Driving Beyond 2020
Honda	Self-Driving on the Highway by 2020
Hyundai	Available for: Highway 2020, Urban Driving 2030
Renault-Nissan	2020 for Autonomous Cars in Urban Conditions, 2025 for Truly Driverless Cars
Tesla	Self-driving cars by the end of 2020
Toyota	Self-Driving on the Highway by 2020
Volvo	Self-Driving on the Highway by 2021

In addition to the above, on July 2019, a joint effort of two major car manufacturers led to obtaining approval for driverless parking (SAE Level 4) without human supervision [43].

It should be noted that although the exemplary and non-exhaustive selections in the tables D.1 and D.2 are not intended for direct one to one comparison but they tend to reveal a general discrepancy between the 2016 predictions and the current state-of-play.

In 2016 it was estimated by the industry that autonomous vehicles would be on the roads in the early 2020s, but this has not materialized yet, as most manufacturers do not seem to be close to achieving true Level 5 autonomy. Instead, the targets for the near future are now more often aiming for conditional autonomy of vehicles with fully automated vehicles in most cases expected to be introduced later in the future, towards 2025.

Growing numbers of automotive experts and company executives state now publicly that self-driving cars will not arrive as soon as it was envisaged, as industry overestimated the arrival of autonomous vehicles. [88]. Even the ones that do not seem to waver from their initial statements acknowledge that the vehicle's "applications will be narrow, what we call geo-fenced, because the problem is so complex" [89]. In our opinion, the following sentence cited from the literature, provides the best reflection on the current status, “Automated vehicles are not yet ready to operate without human supervision [14], [26].

The introduction of high automation will be evolutionary to address, in the first instance, lower complexity problems, such as motorway driving, and gradually addressing more complex driving scenario [3],[90], and it will most likely radically affect initially certain use cases such as e.g. urban shared mobility as most Level 4 vehicles in existence (operating usually an urban environment where top speeds reach 50 km/h in geo-fencing mode) are geared toward ride-sharing [91].

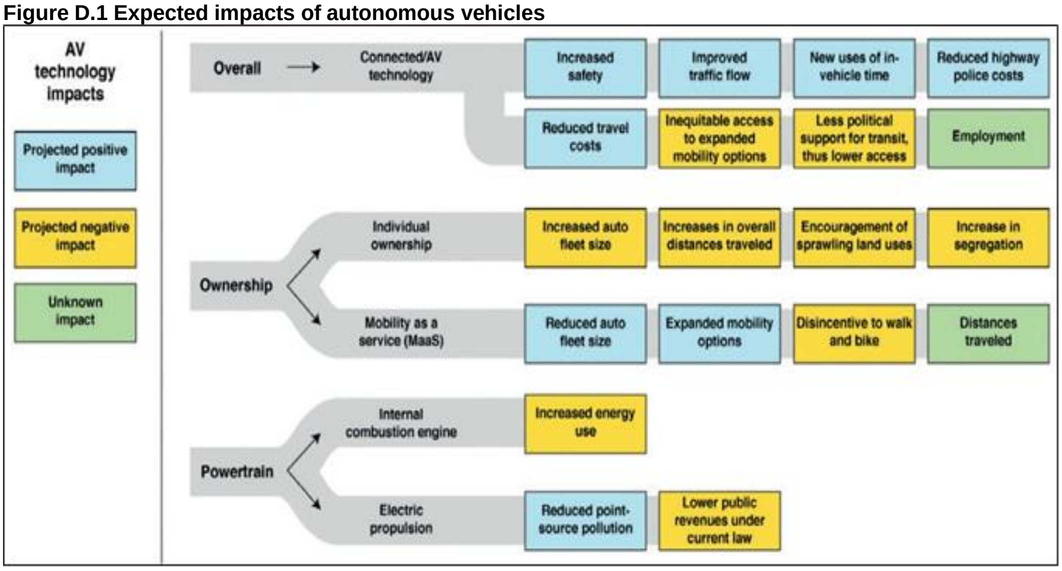
Level 1 (e.g. Adaptative Cruise Control, Park Assist) and Level 2 functions (e.g. Traffic Jam Assist) are currently available on many vehicles (see [4] for definitions). Some companies and public authorities are implementing Level 4 pilot projects, which means that vehicles can only handle certain speeds and certain terrain and mostly drive in a dedicated area. Most experts acknowledge that significant progress is needed before Level 5 automation is reliable, tested and approved [51].

According to the most recent forecasts, self-driving cars will gradually emerge on the roads (urban and motorway), around 2030 and fully autonomous cars (even for urban environment) will become available from 2040 and onwards [44]. Further, different applications of autonomous driving, such as truck platooning, could come into existence at a faster pace. Several pilot projects have taken place over the past few years and projects like ENSEMBLE will implement and demonstrate multi-brand truck platooning on European roads over the next three years. Its deployment on European highways could start as early as 2022. Nevertheless, there are still technological and regulatory challenges to be addressed mainly regarding to safety systems [52]. It is also forecasted that, by 2050, vehicles will be automated and shared [4], [37], [98] highlighting that there are a lot of uncertainties in forecasting the development of CAD.

Possible impacts

Possible CAD impacts (positive and negative) are shown in pictorial form in Figure D.1, created by the MIT Urban Mobility Lab.

Figure D.1 Expected impacts of autonomous vehicles



Source: MIT Urban Mobility Lab.

Overall, autonomous vehicles are expected to increase safety (especially in the case of wide-scale deployment) with the potential to also improve traffic flow, while it can enable new uses of in-vehicle time and reduce travel costs. There could also be potential negative effects such as inequitable access to expanded mobility options, due to concentration of services to densely populated areas.

Also, the introduction of the new mobility services could possibly result in less support for public transit and subsequently to lower accessibility, if proper public policies are not applied [56],[96]. Further, autonomous vehicles bring also the potential to shift ownership models as the increased connectivity and autonomous functions of vehicles create the stimulus for new business models as can be seen by the development of shared economy platforms [80]. When it comes to individual ownership, a cascade of negative impacts can be noticed while a shift to Mobility as a Service (MaaS) results in reduced vehicle fleet sizes and expanded mobility options.

As vehicle automation will eventually be applied to private cars or public transport systems, researchers and practitioners have been weighing the advantages and disadvantages of both uses of vehicle automation. Certainly, the future can be a mix of both uses [54]. Shared fleets of automated vehicles (e.g. as robo-taxis) or car-sharing fleets can bring a significant reduction in the number of cars on the road, however these benefits run the risk of being countered by increased trip frequencies and lengths as a result of improved transport services. Shared fleets, integrated with traditional public transport result in a better urban environment with less noise and pollution, improved traffic efficiency and freer urban space for other purposes [41], [55], [65].

Automated Vehicles and new mobility paradigms, such as shared mobility, can potentially improve equity and access to transportation given of course that also the right policies will be implemented to take into account the lower-income segments of the population [58]. Affordability of CAD functions is expected to be another key success factor and the impact on the users in terms of costs and benefits is essential [57].

The path of the introduction of new business models and how it is going to reshape the provision of transport services and the functioning of the economy overall is yet unclear. Existing literature [11], [12], [56], [69], [70], [94], [95], produces mixed views on the overall impact of these technological developments to the overall levels of employment. Changes in employment could follow a positive direction with the creation of new, higher level, better paid jobs, but they could as well follow the opposite direction where technology replaces many of the existing jobs.

It has proven difficult to determine the number of jobs at risk by automation, since small changes in the estimated approach could yield significantly different outcomes. As an example, the 2017 study on the Future of Skills: Employment in 2030, places 20% of workers in the vulnerable category. In contrast, 47% are cited at risk in a 2013 study on The Future of Employment [68],[69],[85]. Between 0% and 30% of the global workforce could be displaced by automation in general, depending on the pace and scope of the adoption, according to a note on the impact of AI and Automation on the future of Work [104]. The same study however predicts a possible increase of labour demand of between 21 and 33% of the global workforce to 2030 which would offset the amount of jobs lost.

More concrete estimations can be found for truck drivers. Truck driving is a profession that is expected to be considerably impacted by the advent of CAD technology. In this respect, CAD could affect a large number of the current transport work force. There are various estimations on the extent and speed at which transport jobs will be affected. For instance; the International Transport Forum (ITF) estimated in 2017 that the current 3.2 million truck-driving jobs in Europe may decrease to 2.3 or even to 0.5 million by 2040 according to different scenarios [11]. In the US and Europe combined, it is estimated that automated trucks could reduce the demand for drivers by 50-70% by 2030. Up-to 4.4 million of the projected 6.4 million professional trucking jobs could become redundant. On the upside, it is envisaged that automated trucks could potentially address shortage of truck drivers, emerging particularly in Europe [21]. A similar US study suggests that automation is likely to have significant negative impact on truck drivers, bus drivers, and taxi drivers [94], [95]. New research indicates a lighter impact than some have predicted estimating that the adoption of autonomous truck technology in the next 25 years, could threaten around 294,000 jobs in US, and a significant number of the jobs at risk are among the best-paying trucking jobs [69],[70].

What seems sure is that important changes lie ahead in the way the profession of professional driver is practised and a part of these jobs can be expected to disappear in the long-term creating a challenge in transitioning the existing workforce to new jobs. Similarly, not only taxi and public transport services, but also jobs in vehicle manufacturing and repair, as well as in parking services, insurances and beyond can expect significant changes in the way their professions operate and potentially in the type and level of employment offered by these sectors.

On the other hand, jobs can be expected to be created in the field of software development, AI and IoT management, but also related to the provision of MaaS services. It should also be noted that automation may create new employment opportunities [12], [21] and access to employment for those in economically depressed regions could be improved with AV transport services [67].

The further deployment of CAD is expected to have a positive overall impact on sectors like automotive, electronics and software and freight transport. Several experts believe that autonomous vehicles will result in an increase in engineering-related jobs and other positions related to the integration of autonomous vehicles into society [11], [56]. Moreover, artificial intelligence can be a key transformative technology for autonomous vehicles, influencing in the near future, most aspects of the auto- manufacturing process [79]. In addition, information and communication technology (ICT) will play a major role in enabling the automotive industry to face the challenges of digitalisation [81], [83]. Whatever might be the case, the future use of automated vehicles would potentially create an immediate need for adaptations in labour market planning [71].

The cost of autonomous vehicles compared to that of conventional cars is high due to their electronic load (sensors and communications). This, in turn, impedes the affordability of this technology especially for the lower-income segments of society [59]. It should be noted that the cost of automation and its potential evolution is currently too uncertain and subject to significant variations. Companies have been reluctant to disclose detailed information regarding the cost of autonomous cars; however available estimates from car manufactures and industry researchers indicate that the cost of self-driving (Level 4/5) equipment for passenger vehicles, could be around $10,000 by 2025 [11,100,103] but this consensus cost estimate could be aspirational and the electronic and SW costs for Level 4/5 vehicles could be significantly higher [99,100].The cost of Components such as Lidar used in current versions of AV technology could decrease by 2030 and technology breakthroughs in solid-state devices may lead to a decrease to the overall system price [101].

Public acceptance of new technologies can often be slow. This is particularly the case for technologies such as those to be used in fully automated (level 5) CAD. Although 58% of European citizens declare being ready to use CAM [14], the same is not the case in the US where 42% of the public said they would never ride in a fully automated vehicle [102]. It is expected that the public will only accept these technologies if they feel confident in placing trust not only in the safety and reliability of the technology but also in its ethical standing and use [53].

Notwithstanding technology, cost and user acceptance, perhaps one of the major limitations to a faster uptake, is regulation. The timeline of adopting and deploying CAD technology depends heavily on the regulatory developments in the next few years. The uptake of CAD is expected to be sped up by the provisions of the European Commission Regulation 2019/543 revising the General Safety Regulation (GSR) and introducing the requirement for new vehicles to be equipped with ADAS systems in the near future. The multitude of legislative, infrastructural and technological barriers between different countries, slowing down the rate of adoption [49], [76] is discussed in the following section.

Policies related to CAD

Europe due to its strong legacy and innovation in ADAS and C-ITS, is well positioned to take a leadership position in the market on CAD [1],[16],[45]. Europe and a number of Member States have released EU-wide as well as national orientations, road maps and/or national guidelines highlighting targets and opportunities and addressing hurdles to facilitate deployment of automated driving and development of vehicle automation [46]. Moreover, many initiatives for large scale testing on public roads are already underway in Germany, France, United Kingdom, Sweden and The Netherlands, which are also supported by the European Commission [26],[84]. Also, a legal framework for AVs, including driving licence equivalents for Autonomous vehicles, has been reviewed in the UK, the Netherlands, and Germany [7], [84].

In the frame of the CARTRE project, a large selection of roadmaps and action plans, as well as pilots, projects and test sites were collected and analysed. The goal was to provide an overview of what kind of actions and/or recommendations in general and for public authorities in particular were being mentioned. In a first analysis a matrix (Figure D.2) was created to indicate how often the Thematic areas of CARTRE were addressed in the documents. The analysis did show that digital & physical infrastructure, safety validation and policy & regulatory needs were the current major themes for road authorities at the time of the study. Another finding was that some topics like human factors or societal aspects (user awareness and social acceptance) did not seem to be much addressed or specifically mentioned across all roadmaps, pilots or projects. A reason could be that they are taken for granted and therefore not being mentioned explicitly.

Figure D.2 Matrix analysis of roadmaps and action plans (CARTRE Project), 2017)

Normalised by category	Policy and regulatory needs, European harmonisation	Socio-economic assessment and sustainability	Safety validation and roadworthiness testing	User awareness, societal acceptance and ethics	Digital and physical infrastructure	In-vehicle technology enablers	Big data, AI and their applications	New shared and automated mobility services	Human factors	Connectivity
Roadmaps EU countries	63%	37%	63%	26%	37%	16%	37%	5%	11%	63%
Roadmaps non-EU countries	92%	38%	69%	31%	54%	31%	38%	31%	23%	46%
Roadmaps platforms	82%	55%	45%	45%	73%	55%	18%	27%	36%	27%
Roadmaps industry	44%	44%	44%	22%	22%	56%	11%	11%	0%	22%
Average	**71%**	**42%**	**58%**	**31%**	**46%**	**35%**	**29%**	**17%**	**17%**	**44%**
Pilots EU countries	28%	67%	67%	33%	22%	39%	11%	17%	17%	33%
Pilots non-EU countries	0%	60%	80%	10%	20%	50%	40%	40%	0%	10%
Project	30%	13%	61%	26%	39%	65%	13%	4%	43%	39%
Test sites	12%	16%	64%	12%	20%	24%	16%	24%	12%	40%
Average	**20%**	**33%**	**66%**	**21%**	**26%**	**43%**	**17%**	**18%**	**21%**	**34%**

Source: CARTRE Project.

Within a more global framework, regarding CAD enabling technologies, support to infrastructure and testing regulations, USA, Japan and South Korea have on-going ITS plans; USA has currently a plan ongoing until 2019 while Japan has an ITS Roadmap in place as of 2011 and South Korea a National ITS Master Plan, which would extend until 2020. USA faces the challenge of harmonising federal and state level regulations; Japan is well underway in the revision of regulations, while Singapore has enacted a more rigorous legislation amendment in support of the development of CAD trials. China established a National ITS Coordination and Management Team and Office in 2000 and local authorities as well as the national government have issued rules for CAV testing [97]. The following table highlights a few key developments regarding CAD in a selection of third countries.

Table D.3 Overview on CAD related policies in third countries

Country	CAD policy developments
USA	• In September 2016, the National Highway Traffic Safety Administration (NHTSA) and US Department of Transport published a Federal Automated Vehicles Policy that acts as a guideline for CAD development in the USA; • As of 2019, 29 States had enacted legislation related to autonomous vehicles; • The United States Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) coordinates the Federally-sponsored research; • The USDOT also develops and issues regulatory and policy rulings to foster the growth of CAVs and other ITS technologies; • However, there is still a challenge of harmonising the fragmentation across the 50 states. The NHTSA is working in this direction and has presented a model policy that can be adopted by all states; • The ITS Strategic Plan 2015-2019 (ITS-SP) presents the next set of priorities under which ITS research, development, and adoption activities will take place. The ITS-SP defines two primary strategic priorities: (1) Realizing connected vehicle implementation and planning for the deployment of connected vehicles across the USA; and (2) Advancing automation, which focuses on the research, development, and adoption of automation related technologies as they emerge; • The NHTSA expects fully automated safety features and highway autopilots after 2025; • In 2018, Waymo (a subsidiary of Alphabet) launched a commercial self-driving taxi service in Phoenix, Arizona.
Japan	• Japan's ITS roadmap and research and development plan was published in July 2012, aimed at reducing traffic congestion by 2020; review and implementation of measures for full-scale prevalence of Green ITS services (by 2020); and review of vehicle-to-infrastructure cooperative systems for developing an auto-pilot system on expressways (from 2012 to 2020); • The MLIT introduced the "ITS spot" technology in 2009, which consists of three basic services: (1) wide-range road traffic information, where car navigation systems can search different road options; (2) safe driving support, where ITS spots provide road traffic information regularly, including traffic safety issues; and (3) electronic toll collection (ETC); • The first public road test of an automated vehicle on a Japanese highway was conducted in November 2013; • In 2014, Japan launched the Cross-Ministerial Strategic Innovation Promotion Program. One of its 10 themes focuses on Automated Driving Systems (ADS); • According to the ADS timeline, Japan expects practical adoption of Level 3 (automated driving systems providing all operations, with the driver only acting in emergencies) to be a reality by the first half of 2020s, with Level 4 (no requirement or driver intervention) being achieved during the second half of 2020s; • In 2019, the Japanese government approved rules for operating SAE level 3 vehicles on expressways, setting fines for using the technology in the wrong conditions and without travel data recorders; • Up to 100 self-driving shuttles are expected to transport visitors around the various Olympic venues for the 2020 Tokyo Olympics; • Japan's goal is to put self-driving cars on the market in 2025.
South Korea	• The South Korean government projects smart vehicles as the next growth engine of the country, as it combines two strong industries: vehicles and IT; • A dedicated division –Advanced Motor Technology Division –has been installed, together with the AV Expert Forum and a dedicated Commercialisation Support Policy was launched that aims to reach partial commercialisation by 2020, and securing world-class technology by 2026;

Country	CAD policy developments
	• Jointly with the Intelligent Transport Society of Korea (ITS KOREA), the Ministry of Land, Infrastructure and Transport launched the ITS Mater Plan 2020. With regard to the transportation aspect, it allocates approximately 3.25 billion EUR and aims to reach zero traffic accident deaths by 2030 through three stages: (1) vehicle-to-infrastructure (V2I) based on safety on expressways; (2) V2I and vehicle-to-vehicle (V2V) based on safety in metropolitan areas; and (3) V2V + vehicle-to-pedestrian (V2P) based on safety in urban areas; • In 2019, the South Korean government announced its plan to complete communications and traffic infrastructure for fully autonomous vehicles by 2024 for major roads; • SAE level 4 should be put to commercial use by 2027.
China	• The Ministry of Science and Technology (MOST) in China established the National ITS Coordination and Management Team and Office in 2000; • Following this step, a number of national researches were established, such as the National Intelligent Transport Systems Centre of Engineering and Technology and the Centre of National Traffic Management Engineering and Technology; • As China is not a signatory of the Vienna Convention, it was able to start deployment of autonomous vehicles earlier than most countries; • Baidu, the Chinese internet search engine group, started developing a 'highly automated' car in 2014 and the Research Institute of Highway of the Ministry of Transport works jointly with Baidu on issues relating to intelligent driving, transportation safety, research into regulations and technology standards; • Although this joint effort is important, multiple ministries have responsibilities on the supervision of CAD. It is considered that China still needs to develop a national framework for autonomous vehicles; • The Chinese Central government issued rules in 2018 that allowed local and regional governments to issue testing permits for CAD, however local governments have published their own rules; • China has restricted its CAD market to foreign competition by placing limits on the use of GPS and other sensors that might gather data usable for espionage; • In June 2018, the Ministry of Industry and Information Technologies issued a set of guidelines to develop a national standards system; • By 2025, at least 30 percent of new vehicles should feature SAE level 2 features and large-scale use of highly autonomous vehicles is expected by the end of the 2020s.[47]

Source: Based on VTT, SPI, Ecorys (2017) Public support measures for connected and automated driving [97].

[47] See: South China Morning Post (2019) China wants 30% of car sales to be autonomous vehicles by 2025, available at: https://www.scmp.com/tech/article/3040417/china-wants-30-car-sales-be-autonomous-vehicles-2025.

The United Nations UNECE WP2.9 World Forum for Harmonization of Vehicle Regulations in Geneva has restructured its organization regarding the development of automated driving in 2018, in order to enhance and accelerate technical regulations addressing safety and environmental performance [26]. Regarding traffic laws, UNECE Global Forum on Road Traffic Safety (WP.1) has also started new activities to amend the Vienna Convention to make the circulation of SAE levels 3 and 4 possible under certain conditions [77]. The adaptation of vehicles and traffic rules should follow a coherent path [28]. The amendment to the 1968 Vienna Convention on Road Traffic in 2016, constitutes a major regulatory achievement towards CAD deployment [64] as it is seen as a precondition to the broad introduction of automated vehicles of higher SAE levels.

As mentioned, a number of countries have passed legislation to allow testing on public roads, but further steps will be required before the vehicles can come into use. The infrastructure needs to be re-engineered to accommodate the interaction with the electronic systems (sensing & communication) of the automated vehicle and future infrastructures should be flexible enough to absorb further changes in vehicles and their technologies [60]. Infrastructure improvements should follow a phased approach during which the first infrastructure changes will be introduced during the AV pilots. In the second phase, additional modifications will accommodate the mixed traffic of AV's and conventional cars. In the final phase the infrastructure should be able to fully accommodate AV traffic [61].

However, questions of liability need to be resolved and regulatory measures to ensure smooth operation must be put in place. A coherent national and European legal framework for CAD needs to be established. This resonates with the desired harmonization for CAD at EU level, and is also voiced in the Gear 2030 Working Group's Final report on the competitiveness and sustainable growth of the automotive industry [18]. In addition, a common European legislation on liability for manufacturers, drivers and third parties should be developed [63]. This should also consider inputs from a number of different industries. Work in this regard is already underway towards the legislative process necessary to introduce the relevant regulation defining the timing of the introduction of fully autonomous vehicles [78]. Importantly, ethical and legal issues may be the largest barrier to autonomous vehicles according to Morgan Stanley [62].

Commercial developments are evolving quickly and at a pace that often exceeds the rate of progress in research, related policies, and regulations. There is indeed a need to define consistent legal framework conditions for cross-border operations of CAV, e.g. for truck platooning [1] and overcoming other legal barriers (e.g. ethics) [53]. Regulations, such as the EU vehicle approval framework, updated in 2018, ensures a real internal market for vehicles since Member States cannot contradict this legislation by adopting national rules [26].

A harmonised, coherent national and European legal framework that addresses the various aspects of CAD is required in order to remove barriers, facilitate CAD testing and promote interoperability. Standardisation, cybersecurity and a harmonized testing methodology should be focal points. The framework should also facilitate CAD introduction in the market and cross-border use, by offering the participating Member States the flexibility for innovation. Moreover, a common EU legislation on liability should be developed since it is greatly affecting the CAD development and deployment. Clear directives on liability for manufacturers, drivers and third parties should be defined for all five levels of automation, with special emphasis at full automation (Level 5) [63], [77], [82].

Main insights from the AVRI implementation

There are many factors that affect CAD development and deployment. KPMG has developed an Autonomous Vehicle Readiness Index (AVRI) which is considering four critical factors: Technology and Innovation, Policy and Legislation, Infrastructure, and Consumer Acceptance. These four factors measure how 25 countries are positioned with regards to their agility to facilitate the development and deployment of CAD. Table D.4 shows the rankings of the top five countries with regard to this index.

Table D.4 Autonomous Vehicles Readiness Index - Rankings of Top Five Countries

Overall Rank	Country	Technology and Innovation	Policy and Legislation	Infrastructure	Consumer Acceptance
1	The Netherlands	10	5	1	2
2	Singapore	15	1	2	1
3	Norway	2	7	7	3
4	United States	3	9	8	6
5	Sweden	6	10	6	4

Source: Richard Threlfall, *Autonomous Vehicles Readiness Index*, KPMG International, 2019 [7].

The Netherlands ranked first in infrastructure and first overall due to its strong performance in many areas. Singapore ranked first on policy and legislation due to their single governing entity on autonomous vehicle regulations; also due to their funding of autonomous vehicles and the adoption of a national standard to promote safe deployment.

Table D.5 Autonomous Vehicle Readiness Index for Major Vehicle Producing Countries

Overall Rank	Country	Technology and Innovation	Policy and Legislation	Infrastructure	Consumer Acceptance
8	Germany	4	6	13	13
10	Japan	5	15	3	18
12	Canada	11	8	16	11
13	South Korea	7	16	4	19
20	China	19	20	18	14
23	Mexico	23	24	22	21

Source: Richard Threlfall, Autonomous Vehicles Readiness Index, KPMG International, 2019 [7].

Germany and Japan – two major automotive manufactures, are ranked lower in the scale despite performing high in the technology and innovation sections, as a result of lower performance in the fields of policy and legislation, infrastructure readiness and consumer acceptance, which are important factors for the introduction of CAD and thus deserve equal attention [7],[27].

CAD landscape

It is not easy to present a holistic overview regarding the landscape of CAD in all its facets to create a common roadmap not only for the technical development, but for the legal development. In our attempt to attain a 360 degrees view we have synthesized a CAD landscape including research projects, initiatives, working groups, and of course events and relevant literature pertinent to the various aspects of CAD. In this section we highlight a few interesting aspects of it.

The EU has launched a number of legislative and policy initiatives among which the “High Level Group for the automotive industry - GEAR 2030” and the Communication entitled "On the road to automated mobility: an EU strategy for mobility of the future”, which is part of the 3rd mobility package released in May 2018 and which launched the development of the “STRIA Roadmap on Connected and Automated Transport (CAT)” published in April 2019. These provide a strategic planning of R&I actions and improve coordination of national and multinational funding programmes [1],[18],[26].

The European Union has a strong history of funding collaborative research contributing to automated driving (including its various societal impacts) as shown in the chart on the next page which provides an overview of the major recent and current European funded projects in CAD and focussing on the topic of interest for this study, the societal aspects.

Table D.6 EU funded (FP7 and H2020) and Member State funded projects addressing societal aspects: user acceptance, ethics and driver training

No.	Project	Description	Date	Pilot - Country	Funding
1	5G-MOBIX	5G for cooperative & connected automated MOBIlity on X-border corridors	27/11/2018 - 27/11/2021	Shandong Academy of Sciences in Jinan (China), Aalto University campus at Otaniemi, in Espoo (Finland), Versailles Satory and between the campus of Paris-Saclay University and Massy-Palaiseau (France), Berlin and Stuttgart (Germany), Eindhoven-Helmond (The Netherlands), Greece – Turkey cross-border, cross-border corridor between Vigo and Porto (Spain - Portugal), Yeonggwang (South Korea)	EU H2020
2	5GCroCo	5G Cross-Border Control	01/11/2018 - 31/10/2021	Metz-Merzig-Luxembourg cross border corridor (France, Germany, Luxembourg), Montlhéry (France), Motorway 19 & Munich (Germany), Barcelona (Spain)	EU H2020
3	AI4EU	Build the first European Artificial Intelligence On-Demand Platform and Ecosystem	01/01/2019 - 31/12/2021	No piloting activity	EU H2020
4	Auto conduct	Adaptation of the automation strategy of autonomous vehicles (levels 3-4) to driver needs and driver state under real conditions.	01/12/2016 - 01/12/2019	France	MS
5	AutoDrive	Advancing fail-aware, fail-safe, and fail-operational electronic components, systems, and architectures for highly and fully automated driving.	01/05/2017 - 30/04/2020	-	EU ECSEL
6	AUTOPILOT	AUTOmated driving Progressed by Internet Of Things	01/01/2017 - 31/12/2019	Tampere (Finland), Versailles (France), Livorno (Italy), Brainport (Netherlands), Vigo (Spain), Daejeon (S. Korea)	EU H2020
7	AVENUE	Design and carry out full scale demonstrations of urban transport automation by deploying fleets of autonomous mini-buses in low to medium demand areas in cities.	01/05/2018 - 30/04/2022	Copenhagen (Denmark), Lyon (France), Luxembourg, Geneva (Switzerland)	EU H2020
8	BRAVE	BRidging gaps for the adoption of Automated VEhicles	01/06/2017 - 31/05/2020	Simulations at FHG Stuttgart (Germany), VTI (Sweden), Linas-Montlhéry UTAC, (France), ACASA Barcelona, (Spain)	EU H2020
9	CARTRE	Coordination of Automated Road Transport Deployment for Europe	01/10/2016 - 30/09/2018	No piloting activity	EU H2020
10	CATS	City Alternative Transport System.	01/01/2012 - 31/12/2013	Strasbourg (France), Formello (Italy) and Ploiesti (Romania)	EU FP7

No.	Project	Description	Date	Pilot - Country	Funding
11	CoEXist	'AV-Ready' transport models and road infrastructure for the coexistence of automated and conventional vehicles	01/05/2017 - 30/04/2020	Milton Keynes (UK), Stuttgart (Germany), Gothenburg (Sweden), Helmond (Netherlands)	EU H2020
12	COMPANION	Cooperative dynamic formation of platoons for safe and energy-optimized goods transportation.	01/10/2013 - 30/09/2016	IDIADA proving ground near Barcelona (Spain)	EU FP7
13	Dreams4Cars	Set up an offline simulation mechanism in which robots by recombining aspects of real-world experience, can produce an emulated world, with which they can collectively interact to safely develop and improve their Perception-Action systems, in particular focusing on the analysis of rare events.	01/01/2017 - 31/12/2019	Jeddeloh and Bassum (Germany), Orbassano near Turin (Italy)	EU H2020
14	Drive2TheFuture	Needs, Wants, and Behaviour of "Drivers" and Automated Vehicle Users today and into the future.	-	Vienna (Austria), Brussels (Belgium), Faaborg (Denmark), Linkoping (Sweden), Versailles (France), Berlin and Karlsruhe (Germany), Rome (Italy), Oslo (Norway), Warsaw (Poland)	EU H2020
15	DriveMe	Swedish projects to study the benefits to society of autonomous driving and for Sweden and Volvo Cars to become a leader in sustainable mobility	01/01/2014 - 31/12/2017	Gothenburg (Sweden)	MS
16	E8 Borealis	Development of interoperable Day1 and Day1,5 services. Test track related to the NordicWay project.	01/07/2017 - 31/12/2020	40-kilometre-long stretch of the E8 in Skibotndalen (Norway)	MS
17	ENSEMBLE	ENabling SafE Multi-Brand pLatooning for Europe	01/06/2018 - 31/05/2021	Test centre Pferdsfeld (Germany), Test centre AstaZero (Sweden), IDIADA test tracks and open road testing (AP-2, AP-7, C-32) in Catalonia (Spain)	EU H2020
18	FABULOS	Pre-Commercial Procurement of Future autonomous bus urban level Operation Systems	01/01/2018 - 31/12/2020	Tallinn (Estonia), Helsinki (Finland), Lamia (Greece), Helmond (Netherlands), Gjesdal (Norway)	EU H2020
19	FutureDRV	Investigates the future of professional driving by taking a look into the tasks and role of professional drivers and their qualification requirements in 2030 and beyond.	01/09/2016 - 31/08/2019	No piloting activity	EU ERASMUS+

No.	Project	Description	Date	Pilot - Country	Funding
20	GATEway	Greenwich Automated Transport Environment. Trials with a fleet of driverless pods providing a shuttle service, automated urban deliveries and remote teleoperation around the Greenwich Peninsula to understand public acceptance of, and attitudes towards, driverless vehicles	01/01/2015 - 31/01/2018	Greenwich (United Kingdom)	Industry, MS
21	Han-sur-Lesse Pilot Project	Trial project with an autonomous shuttle in Han-sur-Lesse (Grottes).	01/08/2018 - 30/11/2018	Han-sur-Lesse (Belgium)	MS
22	ICT4CART	ICT Infrastructure for Connected and Automated Road Transport	01/09/2018 - 31/08/2021	Graz (Austria), Ulm (Germany), Verona (Italy) and cross-border Brennero (A22 Austria-Italy)	EU H2020
23	InDRIVE	Automotive EGNSS Receiver for High Integrity ADAS Applications based on positioning requirements for data acquisition, signal tracking and data fusion	01/01/2016 - 31/12/2017	-	EU H2020
25	inLane	Low Cost GNSS and Computer Vision Fusion for Accurate Lane Level Navigation and Enhanced Automatic Map Generation	01/01/2016 - 30/06/2018	DITCM pilot at Helmond (Netherlands), RACC pilot at Barcelona (Spain)	EU H2020
26	interACT	Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments	01/05/2017 - 30/04/2020	-	EU H2020
27	InterCor	Interoperable corridors providing seamless continuity and a test bed for current and future C-ITS services deployments across Europe	01/09/2016 - 31/08/2019	Motorway sections of E17, R01, E19 between France and the Netherlands via Ghent and Antwerp and the E34 connecting Antwerp with Eindhoven (Belgium, Netherlands, France), A1 motorway up to Lille and the A22 motorway between Lille and the Belgian border. An extension has been added from Lille towards Dunkirk and Calais through the A25 and A16 (France), Europort Rotterdam to the Belgian border (A15 & A16) and the section from Eindhoven to Venlo (A67) and road section between Breda and Eindhoven (A58, A2) (Netherlands, 100 km connected/digital corridor on A102/A2/M2 (United Kingdom)	EU CEF
28	L3Pilot	Piloting Automated Driving on European Roads	01/09/2017 - 31/08/2021	-	EU H2020

No.	Project	Description	Date	Pilot - Country	Funding
29	LEVITATE	Societal Level Impacts of Connected and Automated Vehicles	01/12/2018 - 30/11/2021	No piloting activity	EU H2020
30	MANTRA	Making full use of Automation for National road TRansport Authorities	01/09/2018 - 30/09/2020	No piloting activities	CEDR
31	MAVEN	Managing Automated Vehicles Enhances Network. Develop infrastructure-assisted platoon organization and negotiation algorithms. These extend and connect vehicle systems for trajectory and manoeuvre planning and infrastructure systems for adaptive traffic light optimization	01/09/2016 - 31/08/2019	Helmond (Netherlands), Braunschweig, Peine-Edesse and Griesheim (Germany), Prague (Czech Republic)	EU H2020
32	MHC-ADS	Meaningful Human Control over Automated Driving Systems	01/06/2017 - 01/03/2020	No piloting activities	MS
33	NICHES+	New and Innovative Concepts for helping European Transport Sustainability - Towards Implementation. Guidelines for implementers and policy makers on innovative urban mobility concepts transferability.	01/05/2008 - 30/04/2011	No piloting activity	EU FP7
34	NordicWay 2	Deployment of pilot studies to further develop interoperable Day-1 and Day 1,5 C-ITS services and support infrastructure readiness for connected and automated driving in Denmark, Finland, Norway and Sweden.	01/02/2017 - 31/12/2020	E8 arctic intelligent transport road corridor, Muonio, 10 km test section (Norway, Finland), E8 from Skibotn to the Finnish border, extended area from Skjervøy (Fv866 and E6), E6 to Tromsø, Main road network in Finland, E6 between Oslo and Svinesund (Norway), Gothenburg, Linköping, Uppsala and greater Stockholm (Sweden), Main road network in Denmark	EU CEF
35	PAsCAL	Enhance driver behaviour & Public Acceptance of CAVs. Awareness-driven and large-scale penetration approach to address all issues raised by the majority (if not all) of the general public that hinder the wide market uptake of Connected and Autonomous Vehicles (CAV).	06/01/2019-05/01/2022	Munich (Germany), Lainate (Italy), Madrid (Spain), Gothenburg (Sweden), Luxemburg	EU H2020
36	Pilotprojekt Sion	Testing of an automated Shuttle-Bus on public roads in Sion - first shuttle testing in Switzerland	20/06/2016 - 31/12/2017	Sion (Switzerland)	MS

No.	Project	Description	Date	Pilot - Country	Funding
37	Pilotprojekt tpf Marly	Testing of an automated Shuttle-Bus on public roads in the Marly Innovation Center	21/09/2017 - 31/03/2020	Marly (Switzerland)	MS
38	Pilotprojekt tpf Meyrin	Testing of an automated Shuttle-Bus on public roads in Meyrin (Geneva)	31/05/2018 - 31/05/2020	Meyrin (Switzerland)	MS
39	Pilotprojekt VBSH Nauhausen am Rheinfall	Testing of an automated Shuttle-Bus on public roads in Neuhausen am Rheinfall	02/02/2018 - 31/01/2020	Neuhausen am Rheinfall (Switzerland)	MS
40	SAM	Safety and acceptability of autonomous driving and mobility. 13 experiments for different use cases with the objective to develop and share knowledge about security validation, acceptance and cost-benefit analysis of services.	24/04/2019 - 31/03/2022	France	MS
41	SHOW	SHared automation Operating models for Worldwide adoption. Supports the deployment of shared connected and electrified automation in urban transport chains through demonstration of real-life scenarios to promote seamless and safe sustainable mobility.	01/01/2020 - 31/12/2023	Rouen and Rennes (France), Karlsruhe, Mannheim and Aachen (Germany), Graz, Salzburg and Vienna (Austria), Kista and Linköping (Sweden), Madrid (Spain), Brainport (Netherlands), Brno (Czech Republic), Copenhagen/Ballurup (Denmark), Tampere (Finland), Trikala (Greece) and Turin (Italy)	EU H2020
42	SLAIN	Saving lives assessing and improving TEN-t road networks safety	01/04/2019 - 31/03/2021	2,000 Km of TEN-T roads in 4 different countries - Croatia, Greece (E853), Italy (A2 and A90) and Spain	EU CEF
43	SuaaVE	SUpporting acceptance of automated VEhicles	01/05/2019- 30/04/2022	-	EU H2020
44	Talking Traffic	Accelerate the development, roll out and deployment of traffic light data (cluster 1), process and distribute data for real time information (cluster 2) and make data available via smartphone and navigation devices (cluster 3)	01/10/2016 - 31/12/2020	The Netherlands	MS, Partnership
45	Transforming Transport	Demonstrate, in a realistic, measurable, and replicable way the transformations that Big Data will bring to the mobility and logistics market	01/01/2017 - 31/07/2019	-	EU H2020

No.	Project	Description	Date	Pilot - Country	Funding
46	Trustonomy	Trustonomy (a neologism from the combination of trust + autonomy) aims at raising the safety, trust and acceptance of automated vehicles	01/05/2019 - 30/04/2022	Warsaw (Poland), Poznan Region (Poland) Southern Finland, Versailles (France), Trento (Italy), North Italy roads, Leeds (UK)	EU H2020
47	TrustVehicle	Improved trustworthiness and weather-independence of conditional automated vehicles in mixed traffic scenarios	01/06/2017 - 31/05/2020	Ford Eskisehir test track, (Turkey), Finland	EU H2020
48	vi-DAS	Vision Inspired Driver Assistance Systems. VI-DAS will progress the design of next-generation 720° connected ADAS (scene analysis, driver status).	01/09/2016 - 31/08/2019	-	EU H2020
49	Waterloo Lion Pilot Project	Trial project with an autonomous shuttle at the site of the Lion of Waterloo in Braine-l'Alleud (2,4 km track).	01/10/2018 - 31/12/2018	Waterloo (Belgium)	MS

Source: ARCADE Project Knowledgebase, status May 2020.

The above chart represents a selection of funded projects addressing societal aspects: user acceptance, ethics and driver training identified in the frame of a preliminary analysis of CAD R&I projects, testing and piloting activities relating to Framework Programs from FP5 up to Horizon 2020 or funded by Member States initiatives. The chart has been compiled based on the Knowledgebase[48] that is being developed and maintained by the ongoing EU-funded ARCADE Coordination and Support Action, follow up of CARTRE Support Action, which aims at coordinating consensus building among stakeholders for a harmonised deployment of CAD across Europe. Projects and initiatives are classified according to the thematic areas they are addressing. These thematic domains correspond to key challenges areas that have been identified by the EU-funded CARTRE project together with the ERTRAC CAD Working Group [4]. The list of Research & Innovation projects is being regularly updated by the ARCADE partners in collaboration with the ongoing CCAM Single Platform where most of the Working Groups plan to use the Knowledgebase as a basis for further analysis.

As of July 2020, 209 EU-funded and national R&I projects have been referenced in the Knowledgebase, among which the 49 listed in Table D.8 are addressing user acceptance, ethics and driver training and 25 are working on socio-economic impacts assessment. More comprehensive overviews of CAD related projects in the EU and of smart mobility projects and trials across the world[49] and relevant databases. such as the Transport Research and Innovation Monitoring and Information System (TRIMIS) are also referenced.

As part of its activity related to Research & Innovation Projects concertation and in the frame of the development of the CAD Knowledge-base[50] which includes:

- EU, national and international R&I projects;
- Position Papers;
- Regulation and policies (National, EU, Worldwide):
  - National Testing regulations & licence exemptions (19 EU countries).
- Strategies & Action Plans:
  - EU & International Roadmaps (EU, Authority, MS, Industry);
  - *National Roadmaps analysis (> 50 roadmaps and action plans, > 80 Pilots);*
  - *Situation in emerging markets (7 countries).*
- Standards (Bodies, Liaison, Collection);
- Guidelines and Evaluation Methodologies:
  - FESTA;
  - Impact Assessment;
  - Wiki catalogues;
  - AD Testing and Evaluation Toolkit.
- Data Sharing (Methodology, Dissemination, Storage & access, anonymization);
- Glossary.

The methodologies included in the Knowledge Base correspond to updates of the FESTA Handbook but the plan is to gather information about other methodologies developed and used in Europe and beyond. The FESTA handbook was initially produced by the FESTA consortium (Field opErational teSt supporT Action, 2007–2008) and subsequently updated by the FOT-Net and FOT-Net 2 consortia. The latest update, in 2018, by the CARTRE (Coordination of Automated Road Transport Deployment for Europe) Coordination and Support Action. adapted the FESTA methodology for projects on testing and evaluating automated vehicles.

48 https://knowledge-base.connectedautomateddriving.eu/projects/findproject/.
49 https://imoveaustralia.com/smart-mobility-projects-trials-list/.
50 https://connectedautomateddriving.eu/.

Within the context of this study particular reference should be made to the Cooperative, Connected, Automated and Autonomous Mobility (CCAM) Single Platform initiative.

The CCAM Single Platform, launched in June 2019, is a joint directive of Directorate-General for Mobility and Transport (DG MOVE), Directorate-General for Communications Networks, Content and Technology (DG CNECT), Directorate-General for Internal Market, Industry, Entrepreneurship and SME's (DG GROW) and Directorate-General for Research and Innovation (DG RTD).

The aim of this platform is to advise and support the EC in the area of open road testing and making the link to pre-deployment activities. This is done through the coordination of CCAM research, piloting, testing and deployment activities, in order to increase their efficiency and effectiveness as well as integrate existing fora. The group will also address any issues related to data access and exchange, digital and road transport infrastructure, communication technology, cybersecurity and road safety.

A total of 100 experts in the field of CCAM, from 25 Member States are addressing a different facet of CCAM across the following 6 Working Groups:
- WG1 Develop an EU agenda for testing;
- WG2 Coordination and cooperation of R&I;
- WG3 Physical and digital road infrastructure;
- WG4 Road safety;
- WG5 Connectivity and digital infrastructure for CCAM;
- WG6 Cybersecurity and access to in-vehicle data linked to CCAM.

Sources for the literature review

The following two tables record potential information sources (foremost from literature, but also other sources such as CAD related research projects) for scenario building, impacts and policy options in the area of CAD. Here we present an overview of the reviewed literature for the Literature review.

Table D.7 List of reviewed literature

	Title	Year	Author/Publisher
1	STRIA Roadmap on Connected and Automated Transport - Road, Rail and Waterborne	2019	DG Research & Innovation
2	The future of road transport implications of automated, connected, low-carbon and shared mobility	2019	Biagio Ciuffo, M. Alonso Raposo, European Commission Joint Research Centre (JRC)
3	Transport 2040: Automation, Technology, Employment - The Future of Work	2019	International Transport Workers' Federation (ITF), World Maritime University (WMU)
4	ERTRAC Connected and Automated Driving Roadmap 2019)	2019	Armin Graeter (BMW), Mats Rosenquist (Volvo Group), Eckard Steiger (Bosch), and Manfred Harrer (ASFINAG)
5	Autonomous, connected, electric and shared vehicles. Reimagining transport to drive economic growth	2019	John McCarthy, David O'Keeffe, ARUP Consultancy
6	Tackling Driver Shortage in Europe	2019	World Road Transport Organisation (IRU)

	Title	Year	Author/Publisher
7	2019 Autonomous Vehicles Readiness Index: Assessing countries' preparedness for autonomous vehicles	2019	Richard Threlfall, KPMG International
8	The impact of automated transport on the role, operations and costs of road operators and authorities in Finland	2019	Risto Kulmala, Finnish Transport and Communications Agency (TRAFICOM)
9	The Automotive Industry Pocket Guide	2019	European Automobile Manufacturers' Association (ACEA)
10	Future Implications of Cooperative, Connected and Automated mobility	2018	M. Alonso Raposo et al, European Commission Joint Research Centre (JRC)
11	An analysis of possible socio-economic effects of Cooperative, Connected and Automated Mobility (CCAM) in Europe	2018	M. Alonso Raposo et al European Commission Joint Research Centre (JRC)
12	Socioeconomic Impacts of Automated and Connected Vehicles	2018	6th EU-U.S. Transportation Research Symposium TRB European Commission
13	Societal impacts of automated driving	2018	Pirkko Rämä et al, CARTRE project
14	State of play of connected and automated driving and future challenges and opportunities for Europe's Cities and Regions	2018	European Committee of the Regions Commission for Territorial Cohesion Policy and EU Budget
15	Transport in the European Union-Current Trends and Issues	2018	European Commission, (DG MOVE)
16	Patents and self-driving vehicles	2018	European Patent Office (EPO), European Council for Automotive R&D (EUCAR)
17	System-level impacts of self-driving vehicles: terminology, impact frameworks and existing literature syntheses	2018	Albin Engholm, Anna Pernestål, KTH/ITRL, Ida Kristoffersson, VTI
18	GEAR 2030 – Final Report	2018	European Commission, DG GROW
19	Trilateral Impact Assessment Framework for Automation in Road Transportation	2018	Satu Innamaa et al, Trilateral Impact Assessment Sub-Group for ART EU-US-Japan ITS cooperation
20	Future scenarios on skills and competences required by the Transport sector in the short, mid and long-term	2017	Evangelos Bekiaris, Matina Loukea CERTH/ HIT, SKILLFUL project
21	Managing the transition to driverless road freight transport	2017	Mac Urata- International Transport Workers Federation (ITF), Fuensanta Martinez Sans - (ACEA) and Jens Hügel (IRU)
22	Social and behavioural questions associated with Automated Vehicles	2017	Clemence Cavoli et al (UCL)
23	Connected and Automated Vehicles Skills gap analysis	2017	Workforce Intelligence Network (WIN), ATLAS Center, Uni. Michigan – Transport Research Institute (TRI)
24	Road Transport Automation, Road Map and Action Plan 2016–2020	2016	Aki Lumiaho and Fanny Malin (Finnish Transport Agency)

	Title	Year	Author/Publisher
25	Women's Employment and Gender Policy in Urban Public Transport companies in Europe – WISE II	2016	International Association of Public Transport (UITP),European Transport Workers' Federation (ETF)
26	On the road to automated mobility: An EU strategy for mobility of the future	2018	European Commission COM(2018) 283 final
27	Issues in Autonomous Vehicle Deployment	2018	Bil Canis Congressional Research Service
28	Shifting up a gear Automation, Electrification and Digitalisation and in the trucking industry	2018	Roland Burger Trucking Industry
29	National Road Authority Connected and Automated Driving strategy 2018-28	2018	CEDR Connected and automated driving working group
30	Connected and Automated Vehicles on a freeway scenario. Effect on traffic congestion and network capacity	2018	Michail Makridis et. al
31	EU Road Safety Policy Framework 2021-2030 - Next steps towards "Vision Zero"	2019	Commission Staff Working Document
32	The 2017 Strategy and Digital Auto Report:	2017	PWC
33	SAE International Releases Updated Visual Chart for Its "Levels of Driving Automation" Standard for Self-Driving Vehicles	2018	SAE International
34	Rethinking Car Software & Electronics Architecture	2018	McKinsey& Company McKinsey Center for Future Mobility
35	A Survey of the Connected Vehicle Landscape--Architectures, Enabling Technologies, Applications, and Development Areas	2017	Josh Siegel, Michigan State University, Sanjay E. Sarma Massachusetts Institute of Technology in IEEE Transactions on Intelligent Transportation Systems PP(99):1-16 ·
36	Experts say we're decades away from fully-autonomous cars. Here's why.	2019	Daniel Gessner, businessinsider.com
37	Five trends transforming the Automotive Industry	2019	PWC
38	Safe road transport roadmap	2019	European Road Transport Research Advisory Council (ERTRAC)
39	Impact of Mobility-on-Demand on Traffic Congestion: Simulation-based Study	2017	David Fiedler, Michal Cap and Michal Certick Department of Computer Science, Faculty of Electrical Engineering, CTU in Prague, Czech Republic
40	Analysis of the potential of autonomous vehicles in reducing the emissions of greenhouse gases in road transport	2017	Hubert Iglińskia, Poznań University of Economics and Business, Maciej Babiakb Poznan University of Technology Institute of Combustion Engines and Transport, Poznań, Poland
41	Not If, but When: Autonomous Driving and the Future of Transit	2018	Jerome M. Lutin Independent Consultant
42	Connected Autonomous Electric Vehicles as Enablers for Low-Carbon Future	2019	Binod Vaidya, Hussein T. Mouftah

	Title	Year	Author/Publisher
43	World first: Bosch and Daimler obtain approval for driverless parking without human supervision	2019	Daimler/media
44	Introduction of automation functions in the passenger car fleet	2018	Prognos
45	Future Mobility Services in the UK	2017	TECH UK
46	C-ITS deployment study: Final Report	2019	European Commission
47	A policy framework for climate and energy in the period from 2020 to 2030	2014	European Commission COM(2014) 15 final
48	Artificial Intelligence In Automotive Industry: Surprisingly Slow Uptake And Missed Opportunities	2019	Forbes
49	Digital Transformation of Industries Automotive Industry	2016	World Economic Forum in collaboration with Accenture
50	Advancements, prospects, and impacts of automated driving systems	2017	Ching-YaoChan International Journal of Transportation Science and Technology
51	Autonomous Vehicle Implementation Predictions Implications for Transport Planning	2019	Victoria Transport Policy Institute
52	EU Roadmap for Truck Platooning	2017	ACEA
53	Task Force on Ethical Aspects of Connected and Automated Driving (Ethics Task Force)	2018	Federal Ministry of Transport and Infrastructure
54	Impacts of connected and automated vehicles – State of the art	2019	MANTRA: Making full use of Automation for National Transport and Road Authorities – NRA Core Business
55	AUTONOMOUS VEHICLES: POTENTIAL GAME CHANGER FOR URBAN MOBILITY	2017	UITP
56	Impacts and POTENTIAL benefits of autonomous vehicles	2018	Atelier parisien d'urbanisme (APUR.org)
57	CARTRE -Coordination of automated Road transport Deployment in Europe	2016	Maxime Flament, Davide Brizzolara et al
58	"Social Equity Considerations in the New Age of Transportation: Electric, Automated, and Shared Mobility"	2018	"Kelly L. Fleming American Association for the Advancement of Science JSPG, Vol. 13, Issue 1
59	The Cost of Self-Driving Cars Will Be the Biggest Barrier to Their Adoption	2019	Ashley Nunes, Kristen Hernandez, HARVARD Business Review
60	Transport 2020: Addressing Future Mobility Needs A Report on the Discussion Held by the TRL Fellows	2016	TRL Academy Fellows
61	A new look at Autonomous Infrastructure	2018	Mckinsey
62	Ethical and legal worries form the biggest barrier to autonomous vehicles	2018	CNBC
63	Public support measures for connected and automated driving	2017	European Commission
64	UNECE paves the way for automated driving by updating UN international convention	2016	UNECE

	Title	Year	Author/Publisher
65	DIGITALISATION IN PUBLIC TRANSPORT	2017	UITP
66	Societal consequences of automated vehicles Norwegian scenarios	2019	TØI Institute for Transport Economics Norwegian Centre for transport research
67	On the future of transportation in an era of automated and autonomous vehicles	2019	P. A. Hancock, University of Central Florida, Illah Nourbakhsh, Carnegie Mellon, Jack Stewart, Wired Magazine
68	New analysis says more jobs safer from automation than previously believed	2017	David Fagan, The Conversation
69	The Future of Skills: Employment in 2030	2017	Hasan Bakhshi NESTA Jonathan M. Downing and Michael A. Osborne Oxford University, Philippe Schneider
70	DRIVERLESS? Autonomous Trucks and the Future of the American Trucker	2018	Steve Viscelli UC Berkeley Center for Labor Research and Education and Working Partnerships USA
71	The Potential Implications of Autonomous Vehicles in and around the Workplace	2018	Simone Pettigrew, Lin Fritschi, Richard Norman Curtain University
72	Towards a Reskilling Revolution Industry-Led Action for the Future of Work	2019	World Economic Forum in collaboration withBoston Consulting Group
73	Autonomous Driving Moonshot Project with Quantum Leap from Hardware to Software & AI Focus	2019	Deloitte
74	The Self-Driving Car Timeline – Predictions from the Top 11 Global Automakers	2019	Jon Walker
75	The Self-Driving Car Timeline – Predictions from the Top 11 Global Automakers	2019	https://emerj.com/ai-adoption-timelines/self-driving-car-timeline-themselves-top-11-automakers/
76	How do automakers perform with their self-driving car timeline?	2019	ARCADE project https://connectedautomateddriving.eu/mediaroom/how-do-automakers-perform-with-their-self-driving-car-timeline/
77	4 Big Hurdles for autonomy in smart cities		*Shane Curran* FLEET Europe
78	Position Paper on Policy and regulatory needs, European harmonisation	2018	CARTRE project
79	The race is on for Autonomous Vehicles Global Policy Update	2019	FTI consulting
80	Building smarter cars with smarter factories: How AI will change the auto business	2017	McKinsey Digital
81	The 2019 Strategy& Digital Auto Report	2019	Strategy& PwC Network
82	Why Your Next Car May Look Like a Living Room http://on.wsj.com/2tlCvYp.	2017	Wall Street Journal
83	Legal aspects on automated driving	2017	Adaptive (FP7 project)

	Title	Year	Author/Publisher
84	Digitalization of automotive industry – scenarios for future manufacturing	2016	Steven Peters, Gisela Lanza, (KIT), Jung-Hoon Chun, (MIT)
85	CONNECTED AND AUTONOMOUS VEHICLES	2019	Society of Motor Manufacturers and Traders (SMMT)
86	THE FUTURE OF EMPLOYMENT: HOW SUSCEPTIBLE ARE JOBS TO COMPUTERISATION	2013	Carl Benedikt Frey, Michael A. Osborne, Oxford University
87	Labour Market and Wage Developments in Europe	2019	European Commission DG-EMPL
88	PUBLIC SUPPORT MEASURES FOR CONNECTED AND AUTOMATED DRIVING	2017	European Commission SPI, VTT and ECORYS
89	Ford Taps the Brakes on the Arrival of Self-Driving Cars	2019	Wired.com
90	Despite High Hopes, Self-Driving Cars Are 'Way in the Future'	2019	New York Times
91	Ford CEO Tamps Down Expectations for First Autonomous Vehicles	2019	Bloomberg
92	The r-evolution of driving: from Connected Vehicles to Coordinated Automated Road Transport (C-ART)	2017	Joint Research Centre
93	Where's My Autonomous Car? The 6 Levels of Vehicle Autonomy	2019	Synopsis.com
94	The Employment Impact of Autonomous Vehicles	2017	U.S. Department of Commerce
95	Transport in the European Union Current Trends and Issues	2019	European Commission DG Mobility and Transport
96	Will self-driving cars put cab drivers, truckers out of business?	2016	CBS news
97	The Future of Transportation: Ethical, Legal, Social and Economic Impacts of Self-driving Vehicles in the Year 2025	2019	Mark Ryan University of Twente, Enschede, The Netherlands Springer (online) Publication
98	The Automated Mobility Policy (AMP) Project Is There a Way? Is There Even a Will? Exploring the legal capacity, bureaucratic willingness and capacity, and political willingness and capacity of automated vehicle regulatory development in Toronto, Canada,	2018	JTL Urban Mobility Lab at MIT
99	Public support measures for connected and automated driving	2017	European Commission VTT, SPI, Ecorys
100	Auto Industry braces for electric shock	2017	Morgan Stanley
101	Automotive software and electronics 2030 Mapping the sector's future landscape	2019	McKinsey & Company
102	What it really costs to turn a car into a self-driving vehicle	2017	Quartz.com Steve Levine
103	Self-Driving Automobiles: How Soon And How Much?	2019	Forbes

	Title	Year	Author/Publisher
104	Not everyone is ready to ride as autonomous vehicles take to the road in ever-increasing numbers	2018	CNBC
105	Revolution in the Driver's Seat: The Road to Autonomous Vehicles	2015	Mosquet et al
106	AI, Automation and the future of Work: Ten Things to solve for	2016	McKinsey Global Institute

Table D.8 EU funded (FP7 and H2020) and Member State funded projects addressing societal aspects: user acceptance, ethics and driver training

No.	Project	Description	Date	Pilot - Country	Funding
1	5G-MOBIX	5G for cooperative & connected automated MOBIility on X-border corridors	27/11/2018 - 27/11/2021	Shandong Academy of Sciences in Jinan (China), Aalto University campus at Otaniemi, in Espoo (Finland), Versailles Satory and between the campus of Paris-Saclay University and Massy-Palaiseau (France), Berlin and Stuttgart (Germany), Eindhoven-Helmond (The Netherlands), Greece – Turkey cross-border, cross-border corridor between Vigo and Porto (Spain - Portugal), Yeonggwang (South Korea)	EU H2020
2	5GCroCo	5G Cross-Border Control	01/11/2018 - 31/10/2021	Metz-Merzig-Luxembourg cross border corridor (France, Germany, Luxembourg), Montlhéry (France), Motorway 19 & Munich (Germany), Barcelona (Spain)	EU H2020
3	AI4EU	Build the first European Artificial Intelligence On-Demand Platform and Ecosystem	01/01/2019 - 31/12/2021	No piloting activity	EU H2020
4	Autoconduct	Adaptation of the automation strategy of autonomous vehicles (levels 3-4) to driver needs and driver state under real conditions.	01/12/2016 - 01/12/2019	France	MS
5	AutoDrive	Advancing fail-aware, fail-safe, and fail-operational electronic components, systems, and architectures for highly and fully automated driving.	01/05/2017 - 30/04/2020	-	EU ECSEL
6	AUTOPILOT	AUTOmated driving Progressed by Internet Of Things	01/01/2017 - 31/12/2019	Tampere (Finland), Versailles (France), Livorno (Italy), Brainport (Netherlands), Vigo (Spain), Daejeon (S. Korea)	EU H2020
7	AVENUE	Design and carry out full scale demonstrations of urban transport automation by deploying fleets of autonomous mini-buses in low to medium demand areas in cities.	01/05/2018 - 30/04/2022	Copenhagen (Denmark), Lyon (France), Luxembourg, Geneva (Switzerland)	EU H2020
8	BRAVE	BRidging gaps for the adoption of Automated VEhicles	01/06/2017 - 31/05/2020	Simulations at FHG Stuttgart (Germany), VTI (Sweden), Linas-Montlhéry UTAC, (France), ACASA Barcelona, (Spain)	EU H2020
9	CARTRE	Coordination of Automated Road Transport Deployment for Europe	01/10/2016 - 30/09/2018	No piloting activity	EU H2020
10	CATS	City Alternative Transport System.	01/01/2012 - 31/12/2013	Strasbourg (France), Formello (Italy) and Ploiesti (Romania)	EU FP7

No.	Project	Description	Date	Pilot - Country	Funding
11	CoEXist	'AV-Ready' transport models and road infrastructure for the coexistence of automated and conventional vehicles	01/05/2017 - 30/04/2020	Milton Keynes (UK), Stuttgart (Germany), Gothenburg (Sweden), Helmond (Netherlands)	EU H2020
12	COMPANION	Cooperative dynamic formation of platoons for safe and energy-optimized goods transportation.	01/10/2013 - 30/09/2016	IDIADA proving ground near Barcelona (Spain)	EU FP7
13	Dreams4Cars	Set up an offline simulation mechanism in which robots by recombining aspects of real-world experience, can produce an emulated world, with which they can collectively interact to safely develop and improve their Perception-Action systems, in particular focusing on the analysis of rare events.	01/01/2017 - 31/12/2019	Jeddeloh and Bassum (Germany), Orbassano near Turin (Italy)	EU H2020
14	Drive2TheFuture	Needs, Wants, and Behaviour of "Drivers" and Automated Vehicle Users today and into the future.	-	Vienna (Austria), Brussels (Belgium), Faaborg (Denmark), Linkoping (Sweden), Versailles (France), Berlin and Karlsruhe (Germany), Rome (Italy), Oslo (Norway), Warsaw (Poland)	EU H2020
15	DriveMe	Swedish projects to study the benefits to society of autonomous driving and for Sweden and Volvo Cars to become a leader in sustainable mobility	01/01/2014 - 31/12/2017	Gothenburg (Sweden)	MS
16	E8 Borealis	Development of interoperable Day1 and Day1,5 services. Test track related to the NordicWay project.	01/07/2017 - 31/12/2020	40-kilometre-long stretch of the E8 in Skibotndalen (Norway)	MS
17	ENSEMBLE	ENabling SafE Multi-Brand pLatooning for Europe	01/06/2018 - 31/05/2021	Test center Pferdsfeld (Germany), Test center AstaZero (Sweden), IDIADA test tracks and open road testing (AP-2, AP-7, C-32) in Catalonia (Spain)	EU H2020
18	FABULOS	Pre-Commercial Procurement of Future autonomous bus urban level Operation Systems	01/01/2018 - 31/12/2020	Tallinn (Estonia), Helsinki (Finland), Lamia (Greece), Helmond (Netherlands), Gjesdal (Norway)	EU H2020
19	FutureDRV	Investigates the future of professional driving by taking a look into the tasks and role of	01/09/2016 - 31/08/2019	No piloting activity	EU ERASMUS+

No.	Project	Description	Date	Pilot - Country	Funding
		professional drivers and their qualification requirements in 2030 and beyond.			
20	GATEway	Greenwich Automated Transport Environment. Trials with a fleet of driverless pods providing a shuttle service, automated urban deliveries and remote teleoperation around the Greenwich Peninsula to understand public acceptance of, and attitudes towards, driverless vehicles	01/01/2015 - 31/01/2018	Greenwich (United Kingdom)	Industry, MS
21	Han-sur-Lesse Pilot Project	Trial project with an autonomous shuttle in Han-sur-Lesse (Grottes).	01/08/2018 - 30/11/2018	Han-sur-Lesse (Belgium)	MS
22	ICT4CART	ICT Infrastructure for Connected and Automated Road Transport	01/09/2018 - 31/08/2021	Graz (Austria), Ulm (Germany), Verona (Italy) and cross-border Brennero (A22 Austria-Italy)	EU H2020
23	InDRIVE	Automotive EGNSS Receiver for High Integrity ADAS Applications based on positioning requirements for data acquisition, signal tracking and data fusion	01/01/2016 - 31/12/2017	-	EU H2020
25	inLane	Low Cost GNSS and Computer Vision Fusion for Accurate Lane Level Navigation and Enhanced Automatic Map Generation	01/01/2016 - 30/06/2018	DITCM pilot at Helmond (Netherlands), RACC pilot at Barcelona (Spain)	EU H2020
26	interACT	Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments	01/05/2017 - 30/04/2020	-	EU H2020
27	InterCor	Interoperable corridors providing seamless continuity and a test bed for current and future C-ITS services deployments across Europe	01/09/2016 - 31/08/2019	Motorway sections of E17, R01, E19 between France and the Netherlands via Ghent and Antwerp and the E34 connecting Antwerp with Eindhoven (Belgium, Netherlands, France), A1 motorway up to Lille and the A22 motorway between Lille and the Belgian border. An extension has been added from Lille towards Dunkirk and Calais through the A25 and A16 (France), Europort Rotterdam to the Belgian border (A15 & A16) and the section from Eindhoven to Venlo (A67) and road section between Breda and Eindhoven (A58, A2)	EU CEF

No.	Project	Description	Date	Pilot - Country	Funding
				(Netherlands, 100 km connected/digital corridor on A102/A2/M2 (United Kingdom)	
28	L3Pilot	Piloting Automated Driving on European Roads	01/09/2017 - 31/08/2021	-	EU H2020
29	LEVITATE	Societal Level Impacts of Connected and Automated Vehicles	01/12/2018 - 30/11/2021	No piloting activity	EU H2020
30	MANTRA	Making full use of Automation for National road TRansport Authorities	01/09/2018 - 30/09/2020	No piloting activities	CEDR
31	MAVEN	Managing Automated Vehicles Enhances Network. Develop infrastructure-assisted platoon organization and negotiation algorithms. These extend and connect vehicle systems for trajectory and manoeuvre planning and infrastructure systems for adaptive traffic light optimization	01/09/2016 - 31/08/2019	Helmond (Netherlands), Braunschweig, Peine-Edesse and Griesheim (Germany), Prague (Czech Republic)	EU H2020
32	MHC-ADS	Meaningful Human Control over Automated Driving Systems	01/06/2017 - 01/03/2020	No piloting activities	MS
33	NICHES+	New and Innovative Concepts for helping European Ttransport Sustainability - Towards Implementation. Guidelines for implementers and policy makers on innovative urban mobility concepts transferability.	01/05/2008 - 30/04/2011	No piloting activity	EU FP7
34	NordicWay 2	Deployment of pilot studies to further develop interoperable Day-1 and Day 1,5 C-ITS services and support infrastructure readiness for connected and automated driving in Denmark, Finland, Norway and Sweden.	01/02/2017 - 31/12/2020	E8 arctic intelligent transport road corridor, Muonio, 10 km test section (Norway, Finland), E8 from Skibotn to the Finnish border, extended area from Skjervøy (Fv866 and E6), E6 to Tromsø, Main road network in Finland, E6 between Oslo and Svinesund (Norway), Gothenburg, Linköping, Uppsala and greater Stockholm (Sweden), Main road network in Denmark	EU CEF
35	PAsCAL	Enhance driver behaviour & Public Acceptance of CAVs. Awareness-driven and large-scale penetration approach to address all issues raised by the majority (if not all) of	06/01/2019- 05/01/2022	Munich (Germany), Lainate (Italy), Madrid (Spain), Gothenburg (Sweden), Luxemburg	EU H2020

No.	Project	Description	Date	Pilot - Country	Funding
		the general public that hinder the wide market uptake of Connected and Autonomous Vehicles (CAV).			
36	Pilotprojekt Sion	Testing of an automated Shuttle-Bus on public roads in Sion - first shuttle testing in Switzerland	20/06/2016 - 31/12/2017	Sion (Switzerland)	MS
37	Pilotprojekt tpf Marly	Testing of an automated Shuttle-Bus on public roads in the Marly Innovation Center	21/09/2017 - 31/03/2020	Marly (Switzerland)	MS
38	Pilotprojekt tpf Meyrin	Testing of an automated Shuttle-Bus on public roads in Meyrin (Geneva)	31/05/2018 - 31/05/2020	Meyrin (Switzerland)	MS
39	Pilotprojekt VBSH Nauhausen am Rheinfall	Testing of an automated Shuttle-Bus on public roads in Neuhausen am Rheinfall	02/02/2018 - 31/01/2020	Neuhausen am Rheinfall (Switzerland)	MS
40	SAM	Safety and acceptability of autonomous driving and mobility. 13 experiments for different use cases with the objective to develop and share knowledge about security validation, acceptance and cost-benefit analysis of services.	24/04/2019 - 31/03/2022	France	MS
41	SHOW	SHared automation Operating models for Worldwide adoption. Supports the deployment of shared connected and electrified automation in urban transport chains through demonstration of real-life scenarios to promote seamless and safe sustainable mobility.	01/01/2020 - 31/12/2023	Rouen and Rennes (France), Karlsruhe, Mannheim and Aachen (Germany), Graz, Salzburg and Vienna (Austria), Kista and Linköping (Sweden), Madrid (Spain), Brainport (Netherlands), Brno (Czech Republic), Copenhagen/Ballurup (Denmark), Tampere (Finland), Trikala (Greece) and Turin (Italy)	EU H2020
42	SLAIN	Saving lives assessing and improving TEN-t road networks safety	01/04/2019 - 31/03/2021	2,000 Km of TEN-T roads in 4 different countries - Croatia, Greece (E853), Italy (A2 and A90) and Spain	EU CEF
43	SuaaVE	SUpporting acceptance of automated VEhicles	01/05/2019- 30/04/2022	-	EU H2020
44	Talking Traffic	Accelerate the development, roll out and deployment of traffic light data (cluster 1), process and distribute data for real time	01/10/2016 - 31/12/2020	The Netherlands	MS, Partnership

No.	Project	Description	Date	Pilot - Country	Funding
		information (cluster 2) and make data available via smartphone and navigation devices (cluster 3)			
45	TransformingTransport	Demonstrate, in a realistic, measurable, and replicable way the transformations that Big Data will bring to the mobility and logistics market	01/01/2017 - 31/07/2019	-	EU H2020
46	Trustonomy	Trustonomy (a neologism from the combination of trust + autonomy) aims at raising the safety, trust and acceptance of automated vehicles	01/05/2019 - 30/04/2022	Warsaw (Poland), Poznan Region (Poland) Southern Finland, Versailles (France), Trento (Italy), North Italy roads, Leeds (UK)	EU H2020
47	TrustVehicle	Improved trustworthiness and weather-independence of conditional automated vehicles in mixed traffic scenarios	01/06/2017 - 31/05/2020	Ford Eskisehir test track, (Turkey), Finland	EU H2020
48	vi-DAS	Vision Inspired Driver Assistance Systems. VI-DAS will progress the design of next-generation 720° connected ADAS (scene analysis, driver status).	01/09/2016 - 31/08/2019	-	EU H2020
49	Waterloo Lion Pilot Project	Trial project with an autonomous shuttle at the site of the Lion of Waterloo in Braine-l'Alleud (2,4 km track).	01/10/2018 - 31/12/2018	Waterloo (Belgium)	MS

Source: ARCADE Project Knowledgebase, status May 2020.

Annex E – Stakeholder consultations

Methodology of stakeholder consultations

In this section we present our overall approach to the stakeholder consultation. We start by outlining the two round of interviews and the three workshops.

First round of interviews

During this first round of interviews, we aimed to complement the information gathered through the other stakeholder consultations (scoping interviews and survey) and collect inputs for the design of the scenarios and modelling as well as getting a better understanding on the views of different stakeholder groups about the potential impacts of CAD.

The questionnaire used by project members were tailored to the four different stakeholder categories identified: manufacturers, transport associations/researchers/policy makers, employment associations/researchers/policy makers and transport service providers.

A summary of the main findings from the interviews is included in Section 2.2.5. Overall, interviews touched upon the following main thematic areas related to CAD:

- Timeframe for CAD adoption;
- Critical factors impacting adoption of CAD;
- Take-up of CAD per market segments;
- CAD affected sectors;
- Impact of CAD on employment and skills;
- Key challenges from CAD introduction and potential solutions.

In terms of types of interviewees we targeted interviewees from the following segments of relevant stakeholders:

- Representative associations;
- Academia/research institutes;
- Public sector representatives;
- Vehicle manufacturers;
- CAD or transport service providers;
- Other (e.g. research projects representatives).

Overall, we reached out to more than 60 potential interviewees by e-mail or through personal contacts (e.g. conferences and events. Most interviews were conducted through the phone/online meeting, while only a few were conducted in person. Our team has successfully completed 26 interviews out. The list of completed interviews is presented, together with the full minutes, in Annex J [not published].

Second round of interviews

During the second round of interviews, we pursued two parallel aims. The first was to validate the findings gathered over the course of the study on the features of the four scenarios developed and the social and employment impact of CAD. The second objective was to better understand the views of different stakeholders on potential policy responses and how to ensure a smooth transition in the coming years while CAD deployment is expected to occur.

Our project team conducted the interviews on the basis of an interview questionnaire, consisting of two different sections. The first section, focused the first objective, i.e. validating the four scenarios and the calculated impacts following our distinction between passenger transport, freight transport and other CAD-relevant sectors (e.g. vehicle manufacturing). The second section, focused on the second objective and therefore investigated potential policy measures, distinguished between several dimensions such as those related to the labour market, characteristics of the workforce and on cross-cutting issues. Interviews were conducted in a structured format and the interview questionnaire along with a memo on the different scenarios and list of policy measures were shared beforehand. In addition, interviewees were also encouraged to provide additional information and focus more to the areas of their expertise.

A summary of the main findings from the interviews is included below in this Annex. Overall, interviews touched upon the following thematic areas related to CAD:

- Impacts of CAD section:
  - Timeframe for CAD adoption;
  - Take-up of CAD per market segments;
  - Impacts of European Union's Green Deal and of COVID pandemic;
  - Impact of CAD on business models.
- Policy measures section:
  - Impact of CAD on employment and skills;
  - Prioritisation of policy actions to alleviate negative effects of CAD transition;
  - Main challenges for implementation of these measures;
  - Impacts of said policy measures on other policy areas (e.g. energy, environment).

In terms of types of interviewees, we targeted interviewees from the following segments of relevant stakeholders:

- Representative associations;
- Academia/research institutes;
- Public sector representatives;
- Vehicle manufacturers;
- CAD or transport service providers;
- Other (e.g. research projects representatives).

Overall, in the second round of interviews we reached out to more than 100 potential interviewees by e-mail or through personal contacts (e.g. conferences and events), with appropriate follow-up and reminders. Most of the interviews were conducted through the phone/online conference call, due to the COVID-19 pandemic restricting possibilities to conduct personal meetings. Our team has successfully completed 25 interviews. The list of completed interviews, together with the full minutes, can be found in Annex J [not published].

Questionnaire survey

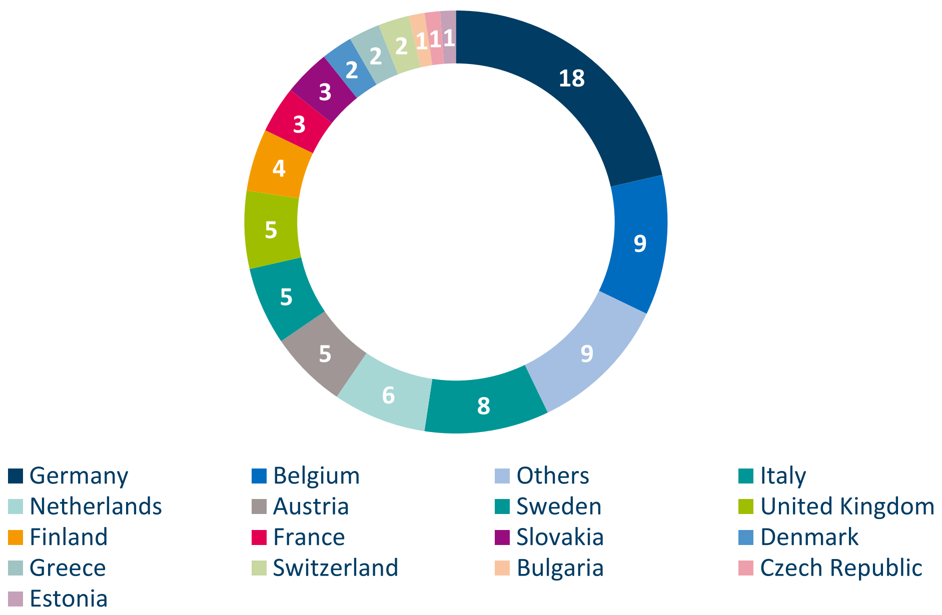
The aim of the survey was to gather information and stakeholder views relevant to the development of the scenarios for the introduction of CAD. This included insights into the expected timeline of introducing connected and autonomous vehicles in different contexts, the expected impacts of its introduction with a specific focus on jobs and skills development as well as the development of existing and emerging EU and global manufacturing and technology clusters that may affect future employment regional patterns.

Through this tool, the study team aims to further understand the context and mechanisms affecting CAD employment and gather information and validating assumptions for the models and scenario's. The answers of the respondents will allow the study team to map their views on the introduction and the take-up of CAD. For this purpose, the survey questions have been tailored to the specific stakeholder groups as different information was relevant to be collected from transport service providers, vehicle/CAD manufacturers policy makers and other stakeholders.

The draft questionnaires presented at the proposal stage have been updated and of the 84 respondents, 54 had reached the end at the cut-off date (10/01/20). Even though, a number of respondents did not completely fill in the questionnaire, nevertheless, their contributions are included in the results to the extent possible. Overall, the level or responses is considered as good.

Respondents geographical background

Figure E.1 Number of respondents to the internet-based survey by country of headquarter



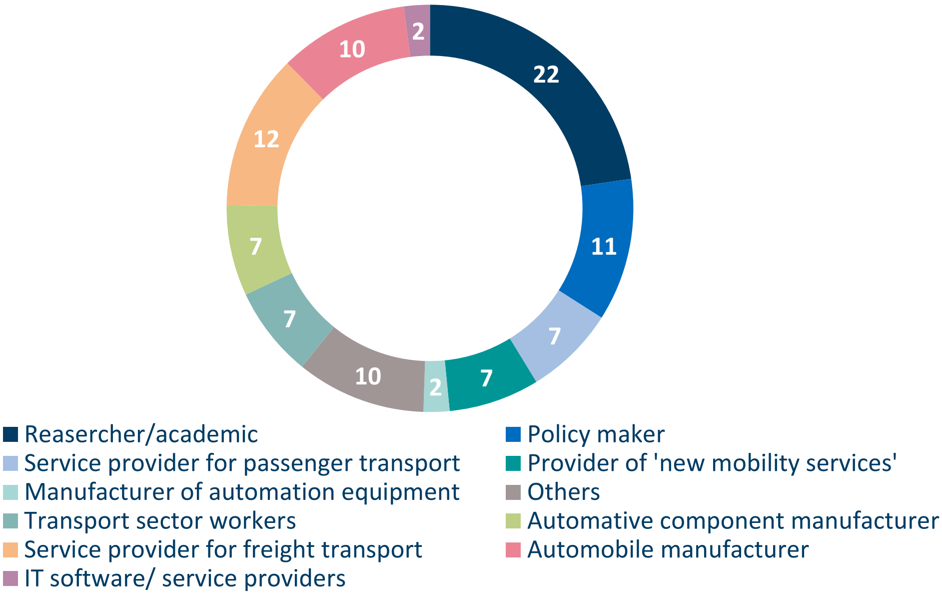
Source: Survey results (2019), Ecorys calculations.
Note: The 'Others" category includes non-EU countries. While not targeted we received responses from Belarus, Saudi Arabia, Turkey and the United States as well as a few undisclosed locations.

The figure shows the distribution of respondents by headquarters' country of their organisation. Of the 84 respondents, 18 work for an organisation based in Germany and 8 are based in Italy (unsurprisingly two of the countries with more advanced automotive industries). Overall, stakeholders from across all different European regions were reached, although participation form Central-European Member states was more limited. Regarding the 'others' category, four indicated the location of their headquarters, the remaining five did not disclose the location. From this four respondents, one is based in Belarus, one in Turkey, one in South Arabia and one in United States (California).

Type of the organisation of the respondents

Out of the 84 respondents, most declared to represent research organisations (22). A substantial share of the respondents (19 out of the 84 respondents) are representing service providers with approximately, two thirds representing freight transport companies (12) and the rest (7) participating on behalf of passenger transport providers. Also, 11 of the respondents are policy makers. The total of respondents working in the manufacturing sector, including automotive, equipment and CAD component, is 19. The figure below shows the distribution of the respondents by type of organisation. Overall, this represents a good representation across the different categories.

Figure E.2 Number of survey respondents by type of organisation[51]



Source: Survey results (2019), Ecorys calculations.

The most relevant parts of the survey findings are introduced later in this Annex, while the full summary of the survey results can be found in Annex F.

First Stakeholder workshop

The first stakeholder workshop took place on the 25th of October 2019. It had the **purpose** to engage with stakeholders in discussing expectations regarding the future of the transport system and the expected impact of CAD on its functioning. The aim was to discuss especially the types of transport services affected and the way in which business models are expected to develop. Further the aim was to dive into the implications for the transport professions of the future in matters of the skillset needed and ultimately the employment levels across the transport domain. The findings of the workshop fed into the assumptions developed to design the scenarios on the development of transport services and business model on which the study is going to base its analysis. Findings will further be used to support the modelling of CAD introduction impacts on vehicle fleets & components.

Second Stakeholder workshop

The second stakeholder workshop took place on the 30th of January 2020. It had the **purpose** to present and discuss the four scenarios, each one representing an alternative case for the deployment of CAD over time: the most and the least favourable conditions for the uptake of CAD, which represent “boundary conditions”, and 2 intermediate cases. For each of the four scenarios, stakeholders were asked to validate the following key aspects:

- Timing of the uptake of CAD vehicles with particular reference to the uptake of automation Level 5 vehicles;
- Whether the uptake takes place primarily in the market of personal mobility or in the market of freight transport or at the same time for both;
- Whether the uptake in the market of personal mobility takes place according to a model of “private mobility” or according to a model of “shared” mobility;

[51] Multiple answers question.

- Different conditions for the circulation of CAD vehicles in urban and rural areas (i.e. traffic regulation). The spatial distribution of CAD deployment with differentiated deployment in “forerunners” and “follower” countries;
- Market share of CAD vehicles for different automation levels;
- Evolution of CAD vehicles’ cost over time;
- Impact of CAD deployment on transport activity for both passengers and freight.

Third Stakeholder workshop

The third stakeholder workshops took place on the 11th of June 2020. It had the first **purpose** to present the identified social and employment impacts of the deployment of CAD technology along the four scenarios for freight and passenger transport. Furthermore, during the workshop policy measures were discussed based on the identified impacts along the following categories of policy measures:

- Awareness and acceptance;
- Education and training (for the current and future workforce);
- Regulatory aspects (e.g. impacts on the driving license directive);
- Measures affecting the social contract between employers and employees;
- Other measures that aim to facilitate a smooth transition towards automated road transport (e.g. addressing spatial mismatch of skill supply and demand).

Final conference

The final conference to present the overall study took place online 15 September 2020. The conference was attended by over 100 participants and during it we presented the employment and social impacts as well as the policy options. In addition, external speakers presented on the perception of citizens towards CAD, the set-up of living labs, future skill needs identified in the SKILLFUL project, and the research & innovation agenda of the CCAM platform. A panel of experts representing transport service providers, transport workers, research, cities, and vehicle manufacturers then debated the social challenges and opportunities of CAD, policy options to address these and set the overall stage for a collaborative approach on working towards a social roadmap for CAD.

Findings from the stakeholder consultations

First round of interviews

The following reporting on interview findings includes a summary of key findings and views of interviewees from interviews conducted until the 20th December 2019.

Timeframe for CAD adoption

All interviewees regardless the sector agree that CAD adoption will increase in the coming years. However, the opinions of interviewees varied regarding the estimated timeframe for the market adoption of different autonomy levels. The following views were shared during interviews with different stakeholders per automation level:

- **SAE 1/2**: These two levels of automation **already exist in the market**. One interviewee with academic research background, shared their estimate in terms of penetration of vehicles of that level. For level 1, penetration rate was estimated at 5% of all vehicles and 1% for level 2;
- **SAE 3:** Interviewees’ views are shared with regards to these automation levels. Firstly, some expressed doubts on whether adoption of level 3 will become widespread or it will get directly to level 4. Regarding the timeframe, interviewees’ expectations varied **from 2 to 10 years** from now. This was confirmed by both interviewees from academia and vehicle manufacturers’ plans.

For the short term estimates, interviewees indicated that they would expect “lighter” versions of level 3 autonomous vehicles;

- **SAE 4:** Regarding level 4 interviewees’ estimates for its deployment indicate in the next **2 to 10 years**. Similar to level 3, more basic applications are expected in the earlier years and more advanced ones towards 2030. However, some researchers express doubt whether level 3 and 4 applications can be safely deployed in mixed traffic environment and suggest that their use will be probably limited to dedicated infrastructure in the beginning;
- **SAE 5:** Estimates on the timeframe for level 5 adoption start **from 15 and go to more than 30 years** from now[52]. While, some interviewees stress that this level of automation will be conditional to social acceptance and unsure whether it will occur at all.[53]

Some interviewees indicated that some CAD applications might become available earlier than their estimates, but in restricted conditions (e.g. confined areas, special dedicated lanes, limited speed). Overall, many interviewees shared the view that current expectations for the deployment of more advanced levels of automation are less optimistic than previous expectations, because the hype during previous years led to overestimation of the CAD potential deployment speed.

Others also highlighted the **need to define clearly the differences between the different automation levels**, because on several occasions perception differ. For instance, some indicated that existing shuttles without a driver are fully autonomous (i.e. level 5), while others disagree with that statement, as existing vehicles claiming to be level 5, cannot deal with any road (e.g. mixed traffic environment) and weather conditions, but function in rather restricted areas under supervision. Thus, different interpretations on what each SAE level constitutes exist. Another interviewee points out that differences in technical requirements between levels 2 and 3 are much wider compared to levels 3 and 4.

Critical factors impacting adoption and CAD deployment

Interviewees identified the following critical factors that have strong correlation with CAD adoption:

- **Technological developments:** Several improvements and new elements need to be deployed to facilitate wider adoption of CAD applications. Technology must demonstrate robustness in all conditions for acceptance and safety. The safety performance of automated vehicles is expected to be critical in developing their acceptance. Specific examples mentioned by interviewees include the following:
  - A simple and user-friendly human machine interface could improve users’ acceptance. This is particularly important for non-professional drivers’ adoption;
  - Current sensors operate within approximately 250 meters. This has an effect on safety issues which limit the allowed speed of autonomous vehicles. Advanced sensors reaching further would play a key role in deployment of level 3-5 applications.
- **Legal framework**: Several revisions to the existing legal framework are necessary to promote the adoption of CAD. According to interviewees the main elements that need to be addressed by this framework include: liability, ensuring legal certainty, standardisation and dealing with data (including access to data by third parties);
- **Electric vehicles and climate change mitigation:** While CAD and electric vehicles seem to go hand in hand so far, it is an open question whether this trend will be continued in the future. Loading capacities might limit the potential of electrification of autonomous vehicles;
- **Key infrastructure**: In terms of key infrastructure 5G deployment is considered as very important for fully automated vehicles. Infrastructure could have major impact on the

[52] As suggested in interviews with an academic in the field of CAD.

[53] This differs slightly from the mostly more optimistic expectations by manufacturers as well as to those by third countries as found in the literature review in Chapter 1. This can be explained by the larger variety of respondents including a good proportion of researchers.

architecture of CAD applications, as those will adjust to available infrastructure. Initial introduction of more advanced automated vehicles is expected to take place in closed environments where the infrastructure will also be adjusted to allow their better functioning. Thus, countries or regions where such infrastructure already exists (e.g. use of Bus Rapid Transit) are likely to proceed faster with CAD deployment;

- **Cybersecurity and data protection**: These elements are crucial for CAD as well as most of new technologies. Interviewees that shared their views indicated that substantial progress is expected to precede CAD deployment as policy actions are already taking place in these areas;
- **Users acceptance, familiarity and awareness**: User acceptance, has a direct positive correlation with potential adoption rates. Acceptance seems to be lower for low-income, lower education people and for women. In addition, awareness of the technology is also crucial, for instance, users are not fully aware of the capabilities level 2 vehicles that are already in the market;
- **Interoperability**: This is another important aspect, as ensuring good Vehicle-to-Vehicle, Vehicle-to-Infrastructure connectivity would facilitate CAD overall adoption;
- **Other:** Elements such as attitude to safety, new technologies and privacy issues might also impact CAD adoption in certain countries/regions. For instance, an interviewee from Germany stated that the high expectations in terms of safety in transport could slow down CAD adoption in the country.

Production clusters

With regards to production clusters, the following are observed:

- Closer collaborations between manufacturers and suppliers are built to mitigate risks from future uncertainties. Interviewees identified the need for closer collaboration also between manufacturers and suppliers as well as manufacturers and clients and other stakeholders;
- In terms of spatial concentration, in Germany, gathering of companies is only observed around the headquarters of big manufacturers (e.g. Audi in Ingolstadt, BMW in Munich and Daimler in Stuttgart). In addition, there is a vibrant CAD start-up scene in Berlin.

CAD costs indication

This question was only addressed to vehicle manufacturers and transport service providers. Interviewees indicated that it is hard to make predictions on the cost structure at this stage, some responses included the following remarks.

Responses from manufacturers:

- The longer period to market access leads to rising development costs. Regarding production costs estimates by manufacturers for SAE level 4 vehicles ranged from an increase of 50-100%;
- A decrease in the total number of vehicles produced could occur as an outcome of increased public transport services.[54] In line with this scenario, one manufacturer indicated that higher maintenance and repair services would be required. Another manufacturer shared a different opinion, stating that repair and maintenance costs will not certainly increase thanks to digitalisation and atomisation of these processes;
- Developing and establishing common standards would be a way to reduce costs for manufacturers of components. The transition to Industry 5.0 could also support further potential cost reductions.

Responses from service providers:

[54] In the first stakeholder workshop (25/10/19), an expected decrease in vehicle production was also associated to change in vehicle ownership models (e.g. increase in shared mobility).

- It is difficult to predict the clear effect in terms of costs when it comes to the introduction of autonomous buses. For instance, in terms of personnel costs bus drivers will be replaced, but service assistants would still be needed in the buses;
- In addition, new cost elements are required for the introduction of CAD, such as digital mapping maintenance, operator neutral control centres, software updates, maintenance and standby personnel for incidences etc. While there are different views on who should bear these costs, an interviewed transport provider indicated that tax payers are most likely to be charged with those.

An interviewee also highlighted that the potentially higher costs should be weighed against long term benefits such as less resource consumption, passenger safety etc.

Take up per market segments

- **Truck platooning**: Interviewees indicated that CAD uptake in trucking is expected to be a leading one in overall CAD adoption, however the potential for reduction in fuel consumption still needs to be proved as available technologies do not prove this sufficiently;
- **Public/private**: Most interviewees expect public transport to play a leading role in CAD adoption, in particular passenger transport with shuttles. This is due to potentially higher costs of CAD applications as well as because of potential new services that can be offered through CAD, but require a critical mass to be successfully adopted and profitable. Adoption of private autonomous vehicles according to many interviewees is expected to follow. Within private users, some groups have higher interest in CAD adoption, these include users with affinity to technology, people with disabilities and senior citizens;
- **Urban/rural areas**: Interviewees indicated that CAD applications may shape both, urban and rural transport. In the following years, CAD applications in urban “closed areas” such as university campuses, hospitals, warehouses, ports etc. are expected. Regarding rural areas, CAD applications may provide a solution to peripheral areas in which local transport has not been profitable so far due to low demand and driver costs. In the long term, in some occasions redesigning a city’s infrastructure to accommodate CAD solutions may be challenging and require major public investment. However, other interviewees argue that the private sector could also contribute to infrastructure development;
- **Car sharing**: The general trend of moving from car ownership to shared cars, as a service. This trend will be invigorated by the introduction of CAD.

CAD affected sectors

Even-though many interviewees stated that it is too early to make assumptions on the implications of the introduction of CAD for different sectors, some of them shared their expectations on future developments:

- CAD will allow new services and new ways of managing the driving tasks;
- Processes in the **manufacturing sector** will be affected by the introduction of CAD applications according to interviewees. For instance, CAD applications for warehousing and packaging could improve efficiency and tasks integration. These applications may replace some currently manual tasks and increase the need for supervision and monitoring services;
- **Existing transport services:** Regarding public transport, some interviewees believe that CAD applications will either be used as upgrades to these services, or as complementary to those, while others support the view that modern transport services will be provided through platforms replacing existing traditional transport services. Regarding smaller private transport solutions, CAD impact is expected to occur in the longer term, for instance for on-demand transport and adapted transport services or goods transport through online platform. In addition, closer collaboration amongst transport service providers is expected;
- Major impact of CAD is expected on the **logistics sector**. Mixed vehicles that carry both people and goods are likely to be introduced according to some interviewees. Automation in loading and unloading trucks could also shape future logistics;

- CAD transport services will require modern **IT services** (e.g. software developing), as well as **support services** (e.g. support services online and offline to assist users of autonomous vehicles);
- Another frequently mentioned sector that will be affected is **insurance services**. Interviewees who mentioned this sector, agree that it will be strongly affected and new insurance schemes will arise. However, the exact impact on the sector is ambivalent.

Employment and skills

Regarding the effect of CAD on employment, overall, most interviewees are uncertain about the net effect in overall employment. Many agree that there will be a shift from low to high skilled employment. However, at this stage a clear trend cannot be observed, but many interviewees stated that at least in the mid-term they do not expect negative impacts on employment. The following possible trends were mentioned by interviewees:

- There is a joint understanding of many interviewees that the direct effects of CAD introduction are an **increased demand of highly qualified workforce** (in particular engineers and ICT specialists) and a **decrease in demand of professional drivers**;
- A large number of employment opportunities will be in the **manufacturing and technical maintenance of autonomous vehicles**. Other highly skilled jobs that might appear would include supervision of autonomous vehicles, traffic monitoring and coordination and other support services;
- Another observation was about the **shift from hardware related activities to higher proportion of software related activities** for each vehicle. This will lead to increased demand for programming, machine learning experts and data analysts or integrated profiles combining those. This demand will be spread beyond manufacturing, and affect any sector dealing with CAD (e.g. enforcement authorities);
- To address the changing skills needs, companies will have to make choice, between recruiting new highly skills stuff, upskilling existing employees and let go or change functions to those whose qualifications and thinking habits are too far away to be employed in main CAD related activities. Possibly a combination of the three will take place;
- Regarding **professional drivers**, many interviewees think that transition to CAD will be very gradual, with sufficient transition period. In addition, during the first transitioning years, professional drivers will have a role in supervising autonomous vehicles or other processes (e.g. logistics, loading and unloading of trucks). Some interviewees refer to CAD as a solution to the current challenge in the bus and truck transport sectors, where lack of drivers is envisaged in the coming years in the EU. For vehicles without drivers, where other personnel will be assisting the operation (e.g. boarding, ticketing, on-board security) more customer oriented skills will be needed;
- **New jobs and functions** will also accompany the introduction of CAD. These shall include on-site services, such as passenger support, security and cleaning services, as well as remote services such as traffic management centres, support call centres, insurance and legal experts. For example, a possible new job function is the one of traffic control operator, similar to the aviation sector;
- **Upskilling of non-professional drivers** will also be a future issue (e.g. for levels two and three, autonomous vehicles);
- Regarding **working conditions,** there are also different impacts observed. Potential reduction of accident rates, will improve the safety of professional drivers and other workers on board (e.g. controllers, loading/unloading staff). In addition, along with the car sharing trend and new business model, more atypical types of employment could become more widespread, with an impact on working conditions (e.g. working hours, social security);

- Another issue that was raised through the interviews, is whether CAD adoption will have an impact on **gender balance in the transport sector**. Along with CAD new functions and skills will be required. This provides an opportunity to include more female professionals in the sector.

The need to attract highly skilled personnel for R&D positions was highlighted by all car manufacturers. Interviewees indicated having several job openings in these areas and already struggling to find suitable personnel for certain positions, such as software engineers. New technologies will require the evolution of current academic fields going for a more interdisciplinary approach than ever before.

Key challenges from CAD introduction and potential solutions
Hereby are summarised the main challenges and potential solutions mentioned by interviewees:
- **Education and training:** Education and training needs will affect most stakeholders involved in the manufacturing and use of CAD. Overall, new skillset would be needed in the future, for which a combination of upskilling experienced workforce and ensuring new younger talents enter the sector. Interviewees mentioned as more challenging the education and upskilling of the following:
  - **Engineers and other technical experts involved in automotive and components manufacturing:** Ensuring highly educated and specialised future workforce to cover positions in R&D and production of autonomous vehicles might constitute a challenge in the near future. The promotion of such education by both the public and private[55] sector is key for ensuring that the industry can employ suitable talents. Close collaboration between education institutes and the industry (e.g. car manufacturers) is important to ensure that skills of young graduates meet future industrial demands;
  - **CAD drivers and supervisors:** Upskilling of drivers will become very relevant especially during the transition period to fully autonomous vehicles;
  - **CAD users:** Training in relation to CAD will become relevant also for passengers, supervisors, operators and any users of autonomous vehicles.
- **(Absence of) legal framework:** A clear and coherent with existing legislations legal framework would be needed to anticipate uncertainties around compliant deployment of CAD. The main issues that need to be clarified in this framework include liability (i.e. between manufacturer, service provider, user, insurer and third parties such as other vehicles), ensuring legal certainty, standardisation (i.e. for production of components for autonomous vehicles), road safety and dealing with data. This framework should be developed hand in hand with researchers and industry representatives. However, as in every new technology, there is a trade-off between quick development of legal framework and its relevance and precision. For instance, the technology should be mature enough to establish standards, otherwise there is the risk to develop frameworks which are obsolete since their beginning;
- **Safety and security:** Interviewees indicated that CAD adoption only makes sense if there is an expected improvement in safety aspects. Advanced technological developments and testing requirements will be essential for proving expected safety enhancement. According to others, security is a bigger issue than safety. For example, people are not willing to let their children use autonomous vehicles by themselves. Human supervision is key in this respect (e.g. security services);
- **Public perception and trust on CAD:** Signs of uncertainty on the future of CAD may confuse potential clients and users and hamper the adoption rate of CAD applications. Awareness raising on the potential benefits as well as the use of CAD would be beneficial according to several interviewees;

[55] For instance, through young talent programmes, such as: https://www.volvogroup.com/en-en/careers/graduate-programs.html.

- Another issue to be addressed is the **data management**, since operators are not always willing to share data with public authorities. An efficient data sharing framework needs to be established to ensure smooth cooperation.

Regarding these challenges some interviewees expressed their optimistic views in addressing those, as the policy discussions have already started in many cases and the transition to connected and automated driving, will take several years and will not occur overnight.

Second round of interviews

The following reporting on interview findings includes a summary of key findings and views of interviewees from interviews conducted until August 2020. The interviews validated the findings obtained during the course of the study and also focused on potential policy measures to be implemented in the main areas identified.

Education and training

On the issue of the (re)education and (re)training of new and existing personnel in the transport sector, the following points have been raised:

- In general, interviewees indicated that there is a need for enhanced **education efforts**, especially with regards to **digital skills**, crucial for new and current employees to acquire the correct set of skills to benefit from the CAD transition;
- Public support could be provided both to companies reskilling personnel and to **labour market intermediaries**. Moreover, **training institutes** (e.g. the ones issuing driving licences) could be involved in the process of redefining the skills needed to work in the transport sector. The result would be to **update educational curricula**, especially for drivers;
- These efforts would be more effective combined with a proper (and potentially mandatory) **social dialogue** involving unions, government, and companies. These could lead to **new definitions of work time and driving time**. One of the more popular suggestions to achieve this is the setting up of new **collaboration forums and/or platforms**;
- Some categories could be particularly hit by the negative effects of CAD uptake, e.g. taxi drivers. New and **alternative business models** would be a possible outcome of the automation of the sector, with digital skills and proper education playing a crucial role;
- Different measures may be needed to help current employees maintaining decent living standards and keeping their current job or being in the condition to start a new one. Here follow some suggestions to achieve this:
  - Start **transition programmes;**
  - Modify and update current medical, health and unemployment **insurances**;
  - Facilitate changes in job categories once CAD is more widespread.

Legal framework and public strategies

Updating the existing legal framework is one of the key aspects necessary for an effective and fair uptake of CAD technologies. These efforts could be supported by proper public strategies to ensure the best results. Stakeholders have provided the following inputs:

- Modifications to the existing legal framework could focus on addressing the following aspects:
  - **Algorithm responsibilities** and liabilities, especially in case of accidents. The legal person or entity responsible could be more clearly defined;
  - Proper regulation on the **infrastructure** needed for the operation of CAD, consistent with smart cities planning;
  - Data management and privacy are a key issue, (more details on it in the next paragraph);
  - Support further research and tests;
  - Harmonise the framework **at EU level**;

- Measures addressing the social dimension (e.g. wage subsidies, taxation) would be relevant not only in the transport sector itself, but also in all the related ones.

- An enhanced body of **statistics concerning CAD effects** could guide stakeholders through data evidences. This could be achieved through the **establishment of a dedicated Observatory**, or of a network of them;
- **Prioritisation of** CAD use-cases, taking into account which ones will be beneficial and which could instead be counter-productive in terms of public acceptance of CAD.

Data management and privacy

Stakeholders agreed the data produced through CAD solutions should be regulated and be GDPR compliant. Potential policy measures, to be conducted at EU-level, are the following:

- Conduct **privacy impact assessments**, to acquire more quality data on the potential effects and risks on privacy of the uptake of CAD;
- Establish a **data protection agreement** on CAD.

Public perception and trust on CAD

CAD as a technology and as a trend is often misunderstood, or unknown to various categories (i.e. employees, consumers, employers). Actions and aspects to keep into account to tackle the issue are here listed:

- Involve the more directly and indirectly affected stakeholders including citizens in **public consultations about CAD**. These will allow citizens to learn more about CAD, a crucial step to increase its social acceptance. Many do not trust automated vehicles, not just in terms of its negative impact on the labour market but for safety concerns;
- **Awareness-raising** campaigns can be used to elevate the status of the transport sector. Nowadays, the sector is not perceived as attractive, in terms of both salary and job to be carried out. CAD has the potential to improve both aspects;
- Awareness campaigns could also aim at **reducing the negative image of CAD**, perceived as a threat to jobs in transport by current employees rather than as an opportunity to improve their status.

Cross-cutting issues

This category of aspects mostly regards social inclusion and how to improve it in the transport sector. The following elements should be taken into consideration when developing policy measures related to CAD:

- **Underrepresentation of women**: the transport sector is currently male dominated. Proper training and attractive hiring practices could be put in place to tackle the issue;
- **Inclusion of people with disabilities**: further research on how CAD could make the transport sector more inclusive for them should be conducted;
- **Other specific groups**: elderly people are an example. Companies and policymakers should ensure they have **equal access to digital services**.

Other aspects

Additional areas indicated by stakeholders are presented here:

- **Environment**: regulation should be compliant with the Paris agreement. The above-mentioned Observatory could also focus on assessing environmental impacts of CAD;
- **Technical aspects:** CAD products should be standardised across the EU to facilitate their adoption and implementation, as well as to facilitate policymakers in drafting consistent rules;
- **Safety and security**: supporting more research initiatives could increase the level of safety of automated vehicles. Moreover, city planners should include motorcycles in cities' security plans, as they have mostly been neglected so far.

Questionnaire survey

The following reporting on survey results includes a summary of key findings and views of respondents conducted until the 10th January 2020.

Timeframe for CAD adoption

Most of the respondents indicate that the level 1/2 of automation will be widely available in 2020 for the four types of transportation (truck automation transport public vehicle automation, private and shared car). Out of 57 respondents, a large part (27) expect the level 3 of automation for truck and private/shared vehicles to be commercially available by 2025. For the level 3 of public transport automation, the respondents are divided since 19 indicate 2025 and 20 indicate 2030. The same ambiguity exists for the level 5 of private car automation as, out of the 56 respondents, 14 indicate 2040 and 13 indicate after 2050.

Critical factors impacting adoption and CAD deployment

As can be seen in the figure below, **technology readiness** is ranked as the factor affecting the most the take-up and acceptance of connected and automated driving, according to 85% of the respondents (61 out of 71) who see this as a very impactful factor for the take-up of CAD[56]. This factor is followed by **safety** which was ranked as an important factor by 82% of respondents (58 out of 71). Regarding **liability** and **legal uncertainty**, 71% of the respondents (51 out of 71) consider these to be highly affecting the transition towards connected and automated driving. Moreover, 77% of respondents (54 out of 71) indicated **infrastructure readiness** to be an important issue while 75% (54out of 71) indicated that the **complexity of operating systems** is an important issue. Many participants considered data protection and cross-country interoperability important but not as many as did previous factors. Finally, an important point mentioned by respondents when asked for other factors was the cost of vehicles and supporting infrastructure which can affect such a transition.

Of those that replied as “other”, 2 out of the 12 respondents highlighted the importance of proving safety which goes beyond perceived safety. In addition, 3 out of the 12 respondents raised the issue of the interaction of automated vehicles with non-automated vehicles and road users. Finally, the costs of vehicles and supporting system (2 out of 12 respondents) and the lack of a clear ownership structure of automated vehicles (1 out of 12 respondents) were mentioned.

[56] According to respondents that rated this factor with scores between 6-10 in a 10-points scale when asked to rate the factors affecting the take-up of CAD.

Figure E.3 Factors affecting the take-up and acceptance of connected and automated driving (on a scale from 1 to 10)

Sub-questions	Resp.	% of responses	avg	med	SD
Technology readiness	71	4 3 7 20 18 39 6	8.55	9	1.85
Other, please specify	21	5 5 5 14 5 33 33	8.21	9	2.37
(Perceived) safety	71	3 4 6 11 23 11 37 4	8.13	8	2.19
Liability issues and legal uncertainty	71	3 8 7 4 4 18 20 28 6	7.64	8.5	2.58
Complexity of operating and supporting (partially) automated vehicles	71	6 8 14 11 18 21 11 6	7.27	8	2.07
Adapting the infrastructure to automated vehicles	71	6 6 4 3 8 13 27 6 23 4	7.21	8	2.48
Data protection	71	3 4 4 8 15 15 13 14 10 8 4	6.29	6	2.31
Interoperability of the systems between different countries	71	7 4 4 11 13 4 17 14 11 8 6	6.13	7	2.62

Average: 7,34 — Median: 8 — Standard Deviation: 2,46

- 1. 1
- 2. 2
- 3. 3
- 4. 4
- 5. 5
- 6. 6
- 7. 7
- 8. 8
- 9. 9
- 10. 10
- \- I don't know

Source: Survey results (2019), Ecorys calculations.

Most of the respondents expect the introduction of automation in different transport services and road types to progress slowly with the exception being the use of automation in public transport on urban roads and rural roads. In the latter, the expectations for a fast increase in employment is slightly prevailing over the view of a slow increase in acceptance as can be seen in the figure below.

Figure E.4 Expected pace of acceptance

Sub-questions	Resp.	% of responses	avg	med	SD
Public transport (taxi and bus) / Rural roads	23	39 48 13	1.55	2	0.5
Public transport (taxi and bus) / Urban roads	23	43 48 9	1.52	1.5	0.5
Truck / Rural roads	23	43 43 13	1.5	1	0.5
Truck / Urban roads	23	52 35 13	1.4	1	0.49
Private car / Rural roads	23	52 35 13	1.4	1	0.49
Private car / Urban roads	23	65 26 9	1.29	1	0.45

Average: 1,44 — Median: 1 — Standard Deviation: 0,50

- 1. Acceptance will grow SLOW
- 2. Acceptance will grow FAST
- \- I don't know

Source: Survey results (2019), Ecorys calculations.

Impacts on transport services

The large-scale implementation of fully autonomous vehicles is expected to produce an increase in the **trip distances** in freight transport according to nearly half of the survey respondents (30 out of 67respondents with 7 ”I don’t know” answers)) with the rest split more or less equally between expecting no impact or a decrease in travel distances. The fully automation of vehicles is expecting to decrease the trip distance in passenger transport by 35 out of the 67 respondents (including 7 “I don’t know” answers). Regarding **trip frequency**, a clearer outlook appears with an increase expected by 47respondent for passenger transport and 40 respondents for freight transport (out of 67 respondents).

On the question which **transport activities** will significantly change due to automation, the urban public transport (43 out of 68 respondents), the taxi services (38 out of 68 respondents) and the long-freight distribution/ car sharing (36 out of 68 respondents for each) stand out. For taxi services, the respondents expect mostly changes in the emergence of new business models. Driverless taxis are seen as a strong competitor to traditional taxi services and will lead to the reduction of prices. The respondents also highlighted the future need for more staff for monitoring, maintenance and customer support. On the other hand, the respondents outline that robotaxis are not feasible until higher levels of automation are implemented. When this will happen, the respondents expect robotaxis to take over the traditional taxi services.

Looking into the **costs of providing transport services**, most of the respondents indicate that driving automation will decrease the costs of transport across the board. The marked exception concerns the use of private cars the costs of which are expected to increase but the respondents did not specify the reason in their answers.

Impacts on transport employment

The survey respondents indicate that driving automation can be expected to lead to a decrease in employment in traditional transport services such as taxi services and coach transport. An even more noticeable decrease can be expected in employment in public urban transport and freight transport with long-haul freight services seen as the ones to face the largest reduction in employment. This reflects also findings from the literature review. It should be noted though that this is not linked to a specific time-horizon. On the other hand, employment in new transport services such as in shared mobility is expected to increase as automated driving further deploys.

Specific challenges brought by this labour force transition have also been identified. Most importantly the need for transition to different jobs within the sector (42 out of 59 respondents), the need for employees to develop new skills (42 out of 59respondents) and the reassessment of professional qualifications (29 out of 59 respondents). According to respondents, CAD deployment needs to be accompanied by changes in educational programs and retraining programs. Some specific recommendations of stakeholders include the suggestion by EUROCITIES that it is important that public authorities define the regulatory framework, operators and service providers provide full transparency on labour conditions and coordination amongst bordering Member States should be taken into account. Also, for IRU, all decisions about the future measures should be taken at the highest political level after a wide research of all possible effects of the introduction of CAD.

Workshops

The workshop results are not presented separately, but can be found in the workshop minutes in Annex G.

Annex F – Disaggregated survey results

Annex G – Workshop minutes

#1 Workshop

Transport services and business models of the future; the impact of Automated and Connected Driving (CAD)

Meeting Minutes - #1 Workshop session

25 October 2019

UITP, Moscow Meeting Room, Rue Sainte-Marie 6, Brussels

Introduction

The meeting was opened by Ioannis Giannelos (Ecorys) who introduced participants to the objective of the meeting and the agenda. The objective of the workshop was to discuss expectations regarding the future of the transport system and the impact CAD is expected to have on its functioning. Specifically, to discuss the *types of transport services* affected and the way in which *business models* are expected to develop. The findings of the workshop will feed in the assumptions developed to *design the scenarios* on the development of transport services and business model on which the study is going to base its analysis. Findings will further be used to support the modelling of CAD introduction impacts on vehicle fleets & components.

He also introduced the overall study and the Consortium implementing the study. Finally, he invited participants to stay involved by responding to the survey, joining the next workshop (January) or by getting in touch with the team.

Potential impact of CAD on transport services and business models

Claudia de Stasio (TRT) introduced attendants to the first part of the workshop. She presented preliminary considerations that the team would use to build the four different scenarios of the development and deployment of CAD technology. In her presentation she highlighted assumptions on the development of labour costs (increased labour costs at SAE levels 3 and 4 dues to higher specialisation of drivers, but reduction of costs for level 5), the role of professional drivers (other tasks, elimination of the profession) and maintenance, vehicle purchase and insurance costs. She then continued by presenting impacts for the various transport services: private cars, ride sharing and vehicle-sharing services, taxi services, urban public transport and freight transport. For each of these she presented various potential impacts depending on different SAE levels. Impacts included for example increased mobility of elderly, disabled or young people, reduction of privately-owned cars, robo-taxis potentially being one of the fastest to be deployed, increased accessibility of rural areas and 24/7 public transport and finally the potential to compensate the shortage in drivers with automation technology.

After presenting these assumptions, she then invited attendants into three discussion groups to discuss the different transport services in more detail.

Round table A – Private car use

The central aspect of the discussion was the timing of the development. **Lifetime duration of new cars** relate with development periods in vehicle markets. These periods will increase because of several reasons: More electric vehicles enter into the market which parts experience less wear and tear. Software updates become more important allowing for an evolution of user experience based on the same vehicle (or hardware). Finally, automated driving improves road performance and better preserves some components like brakes or wheels. It is possible that changes and vehicle

replacement with respect to company vehicles is faster, however the total shares of company vehicles vary strongly between the different EU Member states.
One important factor to consider is the **link between software and hardware**. It is not yet clear whether the added value of automated driving lies more in the hardware or more in the software.

Regarding safety, it is still unclear which relations exists between **automation and accidents**. Although an increased level of security is often associated with automated systems, opposite effects can also occur. For example, it is possible that users of automation levels three and four trust the technology too much. Concentration of drivers in road traffic could decrease, leading to a loss of human control if situations occur that are not yet controlled by automated systems.

Another unclear aspect concerns **driving distance**. If autonomous vehicles (SEA Level 5) provide suitable situations for "moving offices", additional transport mileage might be the result. This depends on the use case and business model. Unlike today's perception of private ownership, future personal transport could lose its strong connotation with vehicle ownership. The main question is, how will people spend their time in transit if they do not need to diver (working, relaxing or what else)? Another question regards the increased possibility to share and make use of vehicles in group. In the end, difference between private and public transport might be less obvious. Indeed, in case of automated ridesharing, increased vehicle usage could be compensated with a higher occupancy rate. Overall, discussants agreed that automation facilitates ridesharing.

In addition, we have to look into the **context of private traffic especially in cities**. For example, the costs of parking permits but also of inner-city tolls has an immense impact on urban traffic. These could be potential policy tools to manage the general usage of vehicles in the future. For instance, by preventing trips without any passengers on board (in case of SAE Level 5).

In general, participants remarked that not only technical and infrastructural aspects are time-consuming and a potential barrier to CAD, but also the development of **social acceptance**.

Round table B – Urban public transport and sharing services

The group on public transport and shared services expected that there would be a **behavioural change of customers** due to better mobility services facilitating increased travel. However, it is unclear how this behavioural change will turn out, since the development of future attractiveness of public transport depends on the policy approach. The CAD scenarios should consider this aspect by integrating different levels of uptake of automated vehicles (AVs) with operational scenarios on how AVs will be regulated and used.

In fact, discussants believe that it is **less about technology but about a political vision** on how to go forward. There is potential for a future with less regulation (or a non-coordinated environment) and private initiatives leading the implementation of automated mobility services which will lead to increased private car use (more traffic, inefficiency) and less bundling of services. An alternative is one with coordinated policy approaches that promotes deployment of AVs in shared fleets of different sizes (e.g. robo-taxis, minibuses) complementing and reinforcing the high capacity public transport network and supporting walking and cycling, rather than privately-owned cars. In the latter scenario, public authorities must therefore take an active role in the roll-out of AVs to ensure their shared use with measures to encourage shared mobility and limit single car occupancy (e.g. road pricing or taxation) and provide 'Mobility as a Service' platforms (as whoever controls the platform controls travel behaviour).

Nevertheless, a **pre-condition is the acceptance** by users. Therefore, investing into large-scale pilots and infrastructure is needed. Key in this respect is the quality of service provided (safety / frequency / flexibility) and the cost of the service for the users. Especially costs are a determining factor in the adoption of CAD technology. However, at this point, there is not much clarity on costs.

From the **labour perspective**, the end result could be a change in employment not in total numbers but into a shift from drivers towards new jobs, therefore investment in skills will be needed. Discussants expected a reduction in drivers but an increase in blue- and white-collar jobs in services and maintenance. The example of the automated metro systems was mentioned where staff has been re-allocated to different functions, mainly dealing with security and customer services.

Particularly, it was discussed that the aim to reduce private car ownership and green our economy would strengthen public transport and mass transit services as the backbone of future transport settings, where cities see strengthened mass transit while rural areas could be integrated via automated shuttles. Participants also mentioned a survey among POLIS members that showed less confidence in the technology and the WISE-ACT project[57], which explores the wider impacts of autonomous and connected transport. Additional sources relevant for the scenarios building mentioned by the participants are: the scenarios developed in the SPACE Project, the ERTRAC Connected Automated Driving Roadmap (March 2019) and the development paths defined in the UITP Policy Brief on automated vehicles (2017).

Round table C – Freight transport

The discussions of the freight transport group focused mainly on the role of the driver. Topics such as psychology and fatigue were discussed as well as the current (and future) shortage of drivers. Similarly, to group B, the need for a vision was mentioned, however in this case it concerned creating a narrative for automation and career paths and training to attract drivers. Moreover, there is a need to think about how SMEs active in trucking can be taken onboard in this development to avoid them being left behind. Furthermore, it was also unclear if SAE level 5 would completely eliminate the need for drivers as there might be specific situations or roads, where professional drivers are still needed. Overall, regulation will play an important role in the adoption and deployment of CAD solutions for freight transport.

One topic discussed was **responsibility in road transport** in case of accidents and how this might change with autonomous vehicles. Insurance costs might increase at first due to the issue of liability. Research shows also great potential for truck platooning[58] and medical brain-research showed no increased fatigue levels in drivers, however concerning higher SAE levels much is based on assumptions and testing needs also to be done in real conditions. Platooning technology is also much more difficult to deploy in Europe than in the USA due to the shorter distances. There was also some scepticism about the efficiency gains and fuel savings from platooning.

An issue with new technologies is that often there is a **lack of training for drivers** with new trucks. If more technology is added, then training levels especially in SMEs need to increase. More education is linked to higher salaries, but would also be an additional barrier to entering an already underserved market. Concern was also raised over the **role of SMEs** as newly trained drivers and maintenance workers are not immediately available and re-education of workers might be needed, which is easier to accomplish for larger companies. The profile of drivers might also change as current drivers are less keen to do other types of work. Drivers might need higher levels of

57 https://wise-act.eu/.

58 https://www.dbschenker.com/de-en/about/press/corporate-news/platooning-in-the-logistics-industry-594294.

education, but the technology behind CAD is so complicated that there will be reliance on IT professionals. Therefore, it will be important to **bridge the gap between engineers and drivers** and provide self-explaining solutions. Moreover, a clear vision on the future of the profession is needed to attract new workers and to test the technology not only at OEMs with their internal highly qualified test drivers but also with real drivers. Once the technology is available, there have then to be also measures to facilitate access to it for SMEs.

Finally, CAVs are only part of the story. **Future logistic hubs** would also need autonomous loading and unloading capabilities. Freight transport would benefit in the shorter-term in confined areas (e.g. hub-to-hub transport) and for repetitive tasks. It will start there and then gradually expand, but before expanding many things need to change first (e.g. regulations, infrastructure).

Employment impacts of changing mobility – a German case study for 2035

Wolfgang Schade and Christian Scherf presented their ongoing study for the Hans Böckler Stiftung on the employment effects of sustainable mobility in Germany by 2035. They developed two future scenarios one on electrification of road mobility and one on multi-modal transport with increased use of rail. They started by presenting the status quo of employment and detailing the sub-sectors of the currently 4.4 million people working in mobility in Germany. In the electrification scenario the amount of private passenger cars kilometres increased while it decreased in the multi-modal scenario. In terms of employment, vehicle manufacturing experiences decreases in employment while public transport and railway manufacturing benefits from the changes. There is also an increase of employment in car sharing and digitalisation of transport (e.g. digital parking services). Overall employment increases but jobs are lost in conventional manufacturing.

Thereafter, they presented their methodology for calculating **downstream** and **upstream** effects. For the downstream effects, a bottom-up analysis was used that collected regional data on local transport demand, local labour markets as well as population numbers and forecasts in German districts. For this they used various databases on companies, employment, car stock, and more to develop a consistent regional database of employment in mobility in German districts. This was then projected until 2035 using certain typecast of German districts. For the upstream effects, they identified hotspots or clusters of vehicle manufacturing as well as potential future hotspots (e.g. areas with a lot of active start-ups). Here a company database as well as national data was used and then broken down to the regional level. Other important aspects were also trade of CAD and the competitiveness of EU CAD industries versus their global competitors. Will the EU be an importer or exporter of the technology? As well as the annual modelling of car numbers per SAE type.

Closing the presentation, they then invited participants to discuss the applicability of this research approach at the European level.

Round table A – Industrial perspective (Upstream)

Question 1: What is the industrial outlook?

The development of efficient algorithms will be a game-changer as it will be the factor enabling autonomous driving. Currently the processing load for autonomous driving leads to doubling the energy use and produces slow decision making. This brings new players in the automotive field, which do not necessary having a connection with transport. It also brings the potential of moving the new industries to different regions in Europe. The relevant IT industries might be more attracted to entrepreneurial clusters (e.g. Berlin) rather than to automotive clusters potentially leading also to a collapse of existing clusters. Although, in some cases they might coexist. After all, it is not only the algorithms that are important, but also the knowledge of the vehicle integration of all “metal” hardware components with IT hard- and software. Vehicle components will need to evolve for the introduction of more advanced SAE levels. IT start-ups will need to cooperate with the traditional vehicle manufacturers while automotive manufacturers are also investing vastly in IT and automation. It is unclear how far an IT oligopoly will develop with the current "winner-takes-it-all" manner seen in Silicon Valley.

Question 2: How does this development affect companies?
Company staff education and structures differ significantly between the automotive and IT industry. It is a concern for EU OEMs that data and programming is becoming more and more important. In addition, increased energy demand for automated vehicles due to the processing load of increased automation is a factor. This might lead to a competitive advantage for manufacturers that control battery supply. Also, the production of IT hardware like energy efficient processors will become an important field to create value-added, though due to high automation it will create limited employment, only.

Question 3: How will this development evolve in the EU compared to the US?
The differences in commuting patterns between the US and the EU (US: 2-3 hours per day) might push for a faster adoption of automation in the USA as this will create lager benefits due to an improved use of the time in the vehicle. Moreover, value of time may differ between European cities. This will also affect the acceptance of new technology. Finally, there is the need for AI and Human-Machine Interface adjusted to safety performance, which might lead to non-global solutions due to different requirements. The difference between US and EU is that in the US the IT industry (together with energy exploration industry) disposes of highest funds to invest into R&D and new product developments, while in the EU (and in particular in Germany) it is the automotive industry (together with chemicals and pharmacy). Thus, the starting point of the regional innovation systems is quite different.

Round table B – Service perspective (Downstream)

Question 1: What are the expected developments of new CAD-related services?
The challenge point are different futures: more services can also mean more jobs in the service sector but it can also mean more traffic, jams etc. The key question is what services we talk about, e.g. driverless public transport, services for private vehicles, infrastructure services or what else. The kind of service has an immense effect on employment. It should always be clear what service is focused on in a special case. For this reason, it is necessary to express clearly the assumptions in the scenarios. We should think also about services, which currently not exist in or with car, e.g. office work: In the future, people can start their work not in the office but already in their cars during their commute, which could become a "mobile office".

Question 2: Which CAD technologies do you rank most important in respect of creating added value and enabling new services?
To answer this question, it is important to know the energy supply system of the new vehicles. Many auxiliary components are based on the fuel or charging system.

Services have always a relation to use of space and infrastructures, especially in cities. The design of roads and highways will be new, when "intelligent spaces" become necessary to create safe environments for driverless vehicles (additional street lines, virtual traffic lights etc.). To build and manage this environment there is a potential demand for new employment.

Automated vehicles will provide much more data in the future than today. This data gets a value for its own. It is still not clear who will reap the benefit of this data. Will the user claim the right to protect the control over their data? Will it possible and acceptable that “third parties” use data for additional services? These questions are still open and should be taken into account to answer the question above.

Question 3: Is the employment impact of CAD-related services possibly approximated by population density (more people, more demand for services, more jobs)?
Services as part of automated transport can be successful in rural areas too, because the non-existing of the driver make public transport cheaper even when the population density is low. Increased use of (automated) public transport forms a basis for new services, like retail, shopping – especially in case of connections between cities and surrounding area. There are additionally services like e-commerce, which induce traffic in cities as well as in rural areas. For that reason, there is no clear relationship between provision of services and population density beside the obvious fact, that more consumers live in towns, which will require more services. Afterall, only the steering of the platform and the management need not to be localised.

Conclusions

Concluding the meeting, Ioannis Giannelos (Ecorys) thanked participants for their active contributions and the very interesting discussions. He reminded participants to stay in touch by taking part in the next workshop on scenario validation in January as well as by responding to the survey.

#2 Workshop

Study on exploring the possible employment implications of Connected and Automated Driving (CAD)

#2 Workshop session

30 January 2020, 13:00 – 17:30

UITP, Moscow Meeting Room, Rue Sainte-Marie 6, Brussels

Meeting report

Introduction

1. This is the second workshop to support the study launched by the European Commission on acquiring detailed knowledge and better understanding of the employment implications of connected and automated driving (CAD);
2. The project has two objectives:
   a. The *analysis and assessment of the short, medium and long term impacts of CAD on jobs, employment, skills and knowledge*, taking into account possible changes in work patterns and the work environment, business and operation models;
   b. The *investigation and elaboration of options in key policy areas*, i.e. jobs, employment, skills, growth, transport and R&I, in order for the EU to take timely action for the safeguarding and enhancement of the positive effects and the avoidance or mitigation of the negative effects of CAD on jobs and employment.
3. The tasks of the project are to collect data and consult stakeholders; draft four scenarios on the future development of CAD; model the impacts of CAD on jobs, employment, skills and knowledge; and prepare policy options to increase positive impacts and limit negative ones;
4. The project has completed its first round of data collection (including the bulk of the literature research) and proceeds now with the drafting of the four scenarios, to be followed by the modelling of the impacts;
5. The objective of this workshop is to discuss with stakeholders the proposed scenarios and invite inputs on key aspects which are necessary for the calibration of the scenarios.

Scenario presentation

6. A description of the scenarios is included in the attached presentation from the workshop;
7. The scenarios should not be misunderstood as forecasts, as they allow the evaluation of possible alternative future events;
8. The scenarios are the inputs for the macro-economic modelling tools ASTRA and NEMESIS applied for the estimation of the impact of CAD on employment and jobs. Both models based on system dynamics, an approach that underlines the relations between complex systems;
9. The four scenarios are developed based on possible situations that lead from the least to the most favourable situation for the development of CAD. Two extreme scenarios have been developed as well as two “intermediate” cases. The four scenarios are presented below:
   a. Scenario 1: Fast, private, unregulated and partially distributed;
   b. Scenario 2: Fast, private, regulated and partially distributed;
   c. Scenario 3: Moderate, shared, regulated and with limited distribution;
   d. Scenario 4: Slow, shared, regulated and with limited distribution.
10. All scenarios are built on top of a Baseline Scenario which is calibrated to reproduce key variables of the EU Reference Scenario 2016 (i.e. population, GDP, transport activity, vehicle fleet, energy consumption, emissions etc.) and have a time period between 2020 and 2050;
11. The main characteristics of the scenarios are described in the PowerPoint presentation, which are distributed to all participants separately.

Discussion

The discussion that followed focused on the characteristics of the scenarios, their thinking behind their design, and the way they are expected to operate. The main points raised and clarifications provided are presented below:

12. Additional sources of information: experts pointed to potential sources of information, such as the LEVITATE (Horizon 2020) project, a UNECE draft regulation on recording of data, DG GROW delegated act, and the ERTRAC roadmap. ACEA also provided their roadmap for the deployment of automated driving in the European Union;
13. The timeframe presented in the scenarios is based on the one hand on the various views of stakeholders (even though they diverge) and on the other hand on the capabilities of the model (cannot go beyond 2050);
14. It was mentioned that the different cultural backgrounds of stakeholders regarding knowledge about CAD shout be taken into account. There are different ways to educate the citizens, the operators or the authorities;
15. There is a large number of factors that can influence the uptake of CAD technology, including among others insurance issues and liability rules, infrastructure readiness and the legal framework. One important factor, that is still unclear, is the responsibility in case of technical breakdowns and traffic accidents. Which part of responsibility lies by the driver, the operator or the manufacture? Also, there is a difference between the time a certain technology is ready and the time when it can be allowed to operate in real conditions. It is clarified that for the scenarios, the time of uptake is not linked to a certain proportion of market share, but it is the time when each technology level is available to the consumer/user;
16. On the definition of the various scenarios among the other possibilities, it was explained that the aim was to obtain two extreme scenarios, that will indicate where the possible future situation may lie. Regarding the differences between the scenarios themselves, a number of distinguishing factors are defined, including speed and level of uptake; cost of ownership; level of private mobility and shared services; number and level of restrictions in the circulation of CAD; and spatial distribution, with frontrunners and followers countries;
17. The parameter of follower and frontrunner countries is to analyse the impacts for those countries where conditions for introduction of CAD are more favourable. It is assumed that followers will have the same path but with a five year delay. A suggestion was to increase the rate of uptake of followers (possibly linking it to volume than time);
18. Scenarios generally present a certain delay in the circulation of CAD in rural areas due to delays in infrastructure development; it could also be considered that rural areas are “frontrunners” and circulation in these areas is allowed before the circulation in urban areas;
19. On regulation the question is raised about who is regulating (public sector or industry)? Also, whether it is the vehicle or the services that is being regulated. It is clarified that the scenarios consider regulation introduced by the public authorities on circulation of CAD vehicles in urban and rural areas. Regulation applies both to vehicles and services. In any case, regulation needs time for implementation into legal frameworks. Some stakeholders ask whether it is possible to change only the degree of regulation while the other aspects are still on the same level (scenarios 1 and 2), despite interactions between other scenario components. The project members explained that scenarios 1 means not that there are no regulations at all, but it is allowed to use driverless vehicles in more areas then in other scenarios;
20. It was mentioned that the presentation suggests a clear separation between the different scenarios components. In fact, there are complex interrelations that is already explained in the reports. This will also be considered for future presentations and graphics;
21. Concerning the inputs and outputs of the model, the ASTRA and NEMESIS models that will follow, require a large number of input variables. It was the proposed methodology of the consortium to develop the specific Scenario Model as a way to generate in a more consistent way parts of those inputs;

22. Experts expressed a concern that no real focus is shown at this stage on societal aspects. It was clarified that the aim of this step is to define alternative future situations and that social impacts (along with others) will be produced at the second modelling stage that will follow;
23. It was indicated that private and shared mobility are not "opposites", as this impression was given in the discussion of the scenarios. In fact, one should consider private vs public (mass transport) and individual vs shared mobility. All scenarios will entail a share of shared (public) and private (individual) mobility. The magnitude of this shares characterizes the different scenarios;
24. There was a long discussion on the need to follow Commission policy for the green deal. However, due to the current level of uncertainty on the exact form this would take, is difficult to make such estimates. It is also uncertain to what extent CAD – on its own – can contribute to a greening goal, and in which way. It has also been pointed out that the aim of the scenarios is to show alternate future paths and not indicate a preferred solution. A possible way forward is to consider elements with possible favourable environmental impacts in each scenario;
25. It was proposed to carry out sensitivity analysis on the input parameters of the scenario model. This would facilitate the identification of impact of individual parameters;
26. From the perspective of some discussion members, it was not always clear, whether aspects like technological readiness or the fleet shares are preceding inputs or final outputs. In other words, what are the independent variables and what are secondary effects? It is important to know, that the outputs of the scenarios are not the total results of the modelling. The scenario output are interim assumptions for the further modelling with the macro-economic tools ASTRA and NEMESIS as well as the synthesis model at the end.

#3 Workshop

Study on exploring the possible employment implications of Connected and Automated Driving

Meeting Minutes - #3 Workshop session
11 June 2020, 13:30 – 16:00
Online Webinar – hosted on WebEx

Part I: Introduction: Exploring the potential employment impacts of CAD

The meeting was opened by the Project Manager Geert Smit (Ecorys), who welcomed the over 50 participants from various stakeholder groups and the European Commission. He then introduced the study *on exploring the possible employment implications of Connected and Automated Driving (CAD)*, the project team and the agenda of the workshop. The first part is a presentation on the employment and social impacts on transport services caused by the introduction of CAD, followed by the second part for which the workshop will split up into breakout sessions discussing policy measures in the areas of:

- freight transport employment;
- public transport employment;
- changing skill requirements; and
- quality of work.

Part II: Presentation of the main results from the impact categories

Wolfgang Schade (M-Five) presented first the four scenarios of CAD deployment in Europe along which the impact results were calculated. The four scenarios are:

- **Scenario 1**: Fast, focused on private transport and unrestricted usage of CAD (maximum uptake of CAD);
- **Scenario 2**: Fast, focused on private transport and regionally restricted usage of CAD (intermediate uptake of CAD);
- **Scenario 3**: Moderate, with emphasis on shared transport and regionally restricted usage of CAD (moderate uptake of CAD);
- **Scenario 4**: Slow, some emphasis on shared transport and regionally restricted usage of CAD (low uptake of CAD).

He then presented **employment impacts based on the modelling exercise** starting with total transport services employment. The main observations were that the impact on the number of jobs is much more important for transport services than for manufacturing as well as that the impact is stronger for freight than passenger services. Furthermore, employment for non-drivers stays rather stable, while mainly drivers are negatively affected. However, across all four scenarios a significant impact of CAD emerges only after 2030. Thereafter, he presented separate results for freight transport, passenger transport, driver and non-driver jobs, and manufacturing. For freight transport, employment demand will actually increase up until 2035, but varying from scenario to scenario fall thereafter. For passenger transport, job levels remain more stable, however depending on the scenario the introduction of CAD changes competition between car and bus transport services. Finally, for manufacturing the models suggested that employment increases in manufacturing, especially in vehicle and electronics manufacturing however to a lesser extent than the job decreases in transport services.

Thereafter, Paulina Pankowska (Ecorys) took the floor to present the qualitative results on the social impacts. She started by presenting the **changing skill requirements** resulting from the transition from conventional drivers who manoeuvre their vehicles to operators who supervise and monitor automated vehicles. In short, drivers require less skills in dexterity, autonomy, routine work, use of machinery and more skills in creativity and resolution, gathering and evaluating information and use of ICT. She then presented the impacts on the **professional and socio-economic characteristics** of the transport labour force. Currently transport services are characterised by an ageing population of drivers as well as a male dominated profession. CAD and its focus on IT skills might attract a younger workforce, while its impact on gender might be more mixed. On the one hand, CAD is associated with skills for which there is also a male dominance (e.g. ICT) and moreover several studies suggest that women seem to be less willing to use automated vehicles. On the other hand, the need for more creativity and resolution might make the profession also more attractive for women. Finally, CAD might also have the potential to increase the average income of automated vehicle operators (relative to conventional drivers) as automated vehicle operators would require a higher level of education. In terms of **cross-cutting impacts**, the topic of driver shortage as well as social inclusion were covered. For the former, high demand for drivers is expected to continue in the short term, but in the longer term less drivers will be needed (in particular in freight transport). For the latter, the impact is not clear cut, however automation might increase job accessibility as well as create a more inclusive society that, from a consumer perspective, can better cater to the transportation needs in rural areas and for people with disabilities.

After the presentations by Wolfgang Schade and Paulina Pankowska, Geert Smit opened the **Q&A** and invited attendants to take the floor to ask questions.

Question #1

Does the composition of forerunner countries affect the overall outcome of the impact assessment?

- There might be spill over effects from the forerunner countries, however the project team would need to check in the models how many forerunner countries there currently are and what the impact would be.

Question #2

The rate of decrease in employment seems to be the same across scenarios. Does this mean that if one would extend the timeline beyond 2050 that all scenarios would end up at similar employment levels?

- The project team explained that the scenarios do not fully align as some usage restrictions would remain (e.g. in certain areas), so the share of drivers would not reduce as dramatically and flatten at a higher level. However, this is based on the assumptions made in the scenarios, which depend heavily on the development of permissions for automated vehicles.

Question #3

Regarding the increase in income for drivers, an academic from the University of Thessaly asked if this would affect current drivers or if they would be slowly replaced by vehicle operators who would receive the higher incomes?

- It was explained that this depends very much on policy choices. If opportunities for retraining are available, then current conventional drivers that retrain for automated vehicle operators may be able to increase their income. However even if this opportunity is provided, there will be winners and loser since not everyone has equal chances to take these opportunities up. Nevertheless, most of today's current drivers would still work during the times where demand for drivers increases, only younger drivers that enter the profession now would experience the effect of automation in their profession. Therefore, it is be important to prepare this younger generation of drivers when attracting them to this profession.

Question #4

What services are included in passenger transport?
- It includes bus, taxi and shared services.

Comment #1

A stakeholder from ACEA commented that the impact results correspond with what the DRIVES project showed. Moreover, the results are in line with their own expectations that the impact will be stronger on freight than passenger transport and that SAE level 4 is not to be expected before 2035. Several factors however influence this development. CAD needs stability as well as adaption of traffic rules, trust and user acceptance for the technology to develop. In this regard, a key question will be how people will cope with the automated decision making processes. The already existing assisted driving functions are very different from a fully automated setting (SAE levels 4 and 5). For these, acceptance will be a big issue especially in a workplace environment, where there are many open questions, for example whether a driver is allowed to do secondary tasks in case of SAE levels 4 and 5.

The stakeholder commented also that the assumed access restrictions to certain automated vehicles in the scenarios would not be a good way forward as it could stop the development of such vehicles overall:
- The project team clarified that these are not access restrictions to the technology but usage restrictions that restrict the operational design domains of such vehicles to certain controllable areas and only slowly let them in areas that could at first involve too many uncertainties (e.g. urban centres). Moreover, it was added that the use of automation features would be restricted, but a vehicle could still access these areas with the driver taking control.

Before closing the Q&A, Geert Smit mentioned that in a next step the team will look into the issue of regional impacts by breaking down the results to NUTS2 levels.

Part III: Discussion on policy measures

After a short break, Geert Smit welcomed participants back to the meeting. He shortly introduced participants to the work of formulating policy options. Based on the identified impacts the project team will consider the challenges (and opportunities) they create and draft policy measures that enhance the positive and mitigate the negative effects. He then explained the set-up of the four breakout session after which the breakout sessions were opened.

Breakout session on freight transport employment

Question #1

Do you think that policy measures can compensate the job losses in freight transport employment?

The response to this first question was mixed with two responding no (CAM, DG RTD), three yes (ITD, TOBB, AEBTRI), and others not voting since they believed the answer would be in between. Respondents clarified that there is the potential that policy measures can compensate job losses at least partially:
- by safety and security reasons that require drivers and hence a smaller decline in demand;
- especially education can compensate job losses;
- Education can take the form of adapting to new requirements or re-education to find new jobs somewhere else.

However, as job losses are extreme, especially in Scenario 1 and 2, some attendees are sceptical that compensation can be reached and job losses of drivers are difficult to avoid. Moreover, US numbers also indicate that the impact on freight transport will be enormous. Attendees agreed though that expectations are very different for conventional and autonomous truck drivers. It was also discussed that the category of non-driver jobs is broad and jobs will hence be affected in many different ways. Therefore, the category of non-drivers needs a closer look and differentiated measures to react on impacts. Finally, attendees think that policy measures are necessary, especially multi-layered measures that guide the CAD-development on different steps along the way (and all the way). These measures are needed from policy-makers but action is also needed from industry, i.e. companies themselves.

Question #2
Are 10 years sufficient to take measures to prepare the sector for changes induced by CAD?

On this question, one attendee thought that it is still too early to introduce policy measures in freight transport regarding job losses as demand is still going up and the numbers show the uptake of CAD-related jobs only in the 2030s. This would still give us sufficient time to think about retraining. Other attendees agreed that it is too early to take measures now, since currently CAD is not commonplace and it is still in development. Therefore, we do not see any concrete impacts and effects yet. However, it is never too early to prepare. On this topic, one attendee added that measures will never be "sufficient", no matter the effort. Agreeing with the need to prepare, one attendee questioned whether 10 years are actually enough to prepare and recommends starting efforts today. Participants reached a consensus that it is time to start thinking and researching for preparation, but that it is difficult to introduce concrete policies as this would need time and consideration based on the findings from research.

Regarding preparation, one attendee suggested taking a step-by-step approach. We should start to test policy solutions in small areas with involvement of all stakeholders and society. By starting at small scale, we then can take lessons learned. This should happen as soon as possible. The example of Living labs was given as a practical measure for this. The purpose of living labs is not only to understand the technology but also its indirect effects. They can also help to create findings that we cannot think off yet (e.g. creation of unexpected indirect jobs):

- *A written remark provided by LNEC at the end of the meeting agreed that living labs are very important to test both technological and non-technological innovations (social innovations, design thinking inspired methods to engage drivers and non-drivers, operators etc.) and built a network for a positive and fair transition and enhance social benefits demonstration.*

Another policy measure that was proposed beyond living labs are transformative super-labs, which operate at a large scale. Their purpose is to test the technology, improve the technology, develop circumstances, research indirect effects and participation of society, and identify new opportunities. After assessing the lessons learned from living labs and super-labs, one can develop policy measures based on the new elements experienced. One attendee added that we can also learn from related technologies (e.g. electric mobility and how charging hubs create new jobs). Finally, one attendee noted that it is important to do research throughout Europe with special focus on societal aspects and not only the technology itself and truck driving.

Manufacturing Employment
Question #3
Should the manufacturing industry handle the CAD-development on its own?

The majority of attendees agrees that the industry should not handle the CAD-development on its own. One attendee added that the industry could do so in theory, but due to the political and ethical questions CAD will create, it is necessary to include policy-makers. In addition, the public should be consulted and included in the debate as the technology serves purposes of society.

Question #4
Which framework conditions should be set to develop a successful and competitive European CAD-industry?
All attendees agreed that policy-makers should develop a framework for CAD-development. The difficult topic of regulation on liability and responsibility in terms of accidents should be debated at large scale and included in the policy framework (e.g. What has to happen in precarious situations? Is the technology used publicly or privately?). Furthermore, one attendee noted that it is maybe necessary for CAD-developers to see a market on CAD-transport services. It can be an idea to bring together transport service labs with CAD-companies to illustrate future demand. For example, it would be possible that when technology companies see an earlier or stronger demand, they increase the speed of market introduction. However, the vehicle industry (in Germany) focuses more on electro-mobility instead of CAD. With money getting scarce now due to COVID-19, CAD technology uptake will probably take longer. Besides that, there are only few manufactures, which can heavily invest in CAD technology. Nevertheless, participants already observe close interaction in pilot projects between users, industry, and government that should be continued and extended in the future.

Breakout session on passenger transport employment

Question #1
The main question of the session was what we should do to react to the presented projections of passenger transport employment.

It was argued that the conditions for CAD depend strongly on the country and the concrete location. A GVB member mentioned the situation in Amsterdam as an example for active policies to reduce the speed of public transport and limiting the use of private cars. These could be conditions for an experimental environment of CAD under real life circumstances. Restrictions in response to the COVID-19 pandemic are an additional factor pushing this transition, because the "re-pedestrianisation" of cities favours better conditions of testing and experiencing CAD. An ACEA representative added that this development has an overlap with the trends of shared economy. Creation of new jobs are possible but maybe these will not be the same people that are working now in public transport. Hence, clear rules to manage this transformation are necessary. Rules like high parking fees for cars in Amsterdam for instance. Mobility agencies of the cities are important actors to set these rules. Cities could deal with several social and environmental issues to build a broader landscape for favourable CAD conditions. With the right setting, making CAD successful would be only a question of time.

One representative from public transport focused on the aspect of job attractiveness, especially for young and new drivers. Currently the working conditions in public transport are difficult because of the peaks in the morning and in the evening. More automation could flatten these peaks and create the basis for balanced working hours. Two important requirements to use these opportunities are developing the speed and range parameters of automated vehicles in public transport. Another participant added that there are two other main factors:

- the first are rules with a lot of cross border issues;
- the second are public transport companies, which need the resources and the motivation for a real transition.

One member of JRC shared some insights from another project about the socioeconomic impacts of CAD. Although the impacts are obviously not as dramatic in the near future as expected, we should not delay preparing for them. It is also necessary to set the right rules, not only with the classic policy measures but also with several socioeconomic instruments like the use of public space. An additional aspect is the role of security to deal with the new situation of driverless vehicles in public transport and public space. This makes clear that the job profile of a driver includes more than only driving, but also as a source of trust and safety for the passengers. If we remove drivers, then we have to think about creating control centres that can fill this gap. Furthermore, additional effort to make the passengers familiar with driverless vehicles are necessary. This effort differs depending on the different social user groups. In the taxi market, the situation is similar because of the transformative potential possibly affecting taxi drivers. However, as this market is more decentralised than the bus market, with more small companies, it is more difficult to enable the retraining across all companies. Finally, CAD may also create opportunities for combined transport modes for both passengers and freight. Therefore, measures should consider both modes.

Breakout session on changing skill requirements

The breakout session on changing skill requirements first focused on the earlier presented description of the *automated vehicle operator*, and that the definition of this occupation (i.e. within the vehicle or outside the vehicle in the form of a traffic control operator). Based on a clearer view on this, skills and qualifications needs can be developed into a training curriculum. It should also be considered that the developments within CAD will not occur as a shock, but will gradually be introduced into the driver profession, which allows for gradual skills development (e.g. through updating regular refresher courses of drivers).

After this first discussion. The issue of how trainings should be organised was raised, i.e. universal or employer-based. From an employer perspective it was indicated that it has to make sense financially to invest in (training for) automated transport, the time and costs required for re-training drivers should be offset by an increase in overall productivity. The attendee added that otherwise transport companies would only invest into this technology and in upgrading their employees' skills if this is supported by government policies. Subsequently, the discussion focused on the role that governments could play within the retraining of drivers. It was noted that CAD might encompass several positive externalities such as solving the driver shortage, decreasing pollution and congestion and increasing safety on the road – which would provide governments with a mandate to intervene and support the training of drivers. Last, it was discussed that the impact of CAD should also be considered beyond the driver occupation when designing policy measures. One example mentioned here was the (predicted) increased demand for traffic controllers.

Breakout session on quality and attractiveness of work

This session started by clarifying the notion that the situation faced by professionals will differ from that faced by private persons, even though currently the full picture may not be visible. Consequently, any measures should consider actors at different levels to ensure that the quality and attractiveness of work is positively impacted.

A future challenge brought forward by the participants was that working conditions of truck drivers might be negatively impacted, as automation would take central role in long distance trips, with the driver only being active for first/last mile trips. This could negatively impact renumeration of drivers and further reduce the attractiveness of work. Moreover, the overall number of truck drivers required could be reduced. Issues related to the quality of life of drivers were also mentioned. Specifically, that automated vehicles would reduce the need for drivers to stop and take breaks.

Attendees raised concerns about the possibility of job-losses. It was considered likely for the sector to experience a short-term decline in jobs. Therefore, unemployment insurance companies should prepare for such a scenario. In addition, a representative from taxi services mentioned that labour standards should be enforced in order to prevent driving jobs from losing the social protections they currently enjoy. Already, people are not interested in joining the sector, also because they perceive it will be revolutionised by near future. The automatization of taxis will not happen suddenly, so the transition period needs to be handled properly. Furthermore, one would need to increase the attractiveness of the sector to female employees as well as younger people. Regarding mitigating measures, the role of the national and regional governments was considered crucial in providing social support to those in endangered jobs, both during a transition period and in the longer term.

The topic of training was also discussed, not only in terms of re-skilling the workforce to adjust to the new operating environment, but also for those who will have to look for alternative employment. Education in technical skills would be important in preparing the new workforce. In particular, more women should be encouraged here to improve gender equality. While CAD in itself is not expected to reduce the gender gap in the driving sector, efficient educational planning could include women, who could be encouraged in acquiring the new set of skills required.

Finally, the discussion focused on raising awareness about the possible impacts of CAD. Here extensive and concrete action should be taken at national level to prepare the general public, the workforce, and also insurance companies. For example, marketing and information campaigns could be useful in promoting CAD-related positions, which might be more attractive for younger people due to the higher set of skills required. In fact, the current insecurity surrounding the whole sector and its futures makes it an even less attractive occupation. Potentially interested people cannot get a clear picture in terms of opportunities, job positions and salaries. Here the timing is important, since marketing strategies targeting younger people would only be possible once CAD technology has arrived on the market. However, national strategies to raise awareness and preparation should be carried out before that moment.

Conclusions

Concluding the meeting, the Project Manager Geert Smit summarised a few of the main points from the meeting and presented the next steps of the project. These are taking in the results from the workshop as well as kicking of a process of consulting stakeholders. Participants are invited to stay in touch with the project team to either take part in the interviews planned for June and July, or hear about the final results to be presented at the final conference (tentatively planned for 15 September 2020). After thanking the participants for their active contributions and the very interesting discussions, he closed the workshop.

#4 Final Conference

Study on exploring the possible employment implications of Connected and Automated Driving (CAD)

Meeting Report – Final Conference
15 September 2020, 10:00-16:00
Online Conference

Morning session on the employment and social impacts of CAD

Introduction

The Project Manager of the study, **Geert Smit** (Ecorys) opened the conference. He stated that while CAD has been researched extensively, there seems to be a lack of real evidence on the actual social and employment impacts. The *study on the employment impacts of CAD* provides this quantitative and qualitative evidence on how CAD will affect road transport. The 16 month study was a collaboration of several partners, including stakeholder organisations (ERTICO, IRU, and UITP), expert partners on scenario and economic modelling (M-Five, TRT and SEURECO), and on technical expertise on the subject matter (VTT, CAM) as well as policy experts (Ecorys).

Thereafter, the Project Officer from the European Commission, **Frank Smit** (DG RTD), provided his opening remarks. He elaborated on the reasons why the European Commission decided to fund this study as part of the work of the Ecological and Social Transitions Unit of DG RTD, namely:

- The EU is transitioning in many ways, most prominent climate change and the European Green Deal with its aim to become the first climate neutral continent;
- New technologies, sustainable solutions and disruptive innovations are critical in achieving these objectives;
- The goal of transition policy is to enable, facilitate and guide the social and political transition to bring about sustainability;
- This is also the case in light of the transition towards CAD in road transport and the social impacts it entails.

Therefore, Frank Smit concluded is it important to investigate these impacts to identify gaps and opportunities to provide information for evidence-based policy making.

Before moving to the presentations, co-moderator, **Stephane Dreher** (ERTICO ITS-Europe) invited **Jacob Bangsgaard** as CEO of ERTICO to officially welcome the participants. He stated that automation, which is a top priority for ERTICO and of great interest to most of its 120 partners, is considered to bring many benefits in terms of safety, efficiency and convenience. But aspects such as digitalisation and AI, including in the mobility sector, are also sometimes considered synonymous with job losses and refocussing of skills. These aspects in fact also open up a range of opportunities for the mobility sector for the future. The focus on opportunities and benefits needs to be balanced by analysis of the new mobility space taking into account jobs in a background of policy, consumer demand and sustainability. Mr. Bangsgaard alluded to the impact of the COVID-19 pandemic, which has led to 'stress-testing' of mobility services. Automation has the potential to provide a number of solutions but the value from the user perspective must also be clear. These societal aspects and user needs are important pillars of the CCAM partnership, which is being set up in the Horizon Europe framework. ERTICO, as an active contributor to the development of this partnership, ERTICO is committed to raising awareness about automated mobility, disruptive technologies and stakeholder needs. He emphasised that, to be optimal, technological advances require sound policies, which is why the present Study is so important.

Presentation 1: Impacts of CAD on the labour market

Wolfgang Schade (M-Five) presented the four scenarios that were developed by TRT on the uptake of CAD, ranging from maximum, intermediate, moderate and low uptake. Based on these scenarios he then presented the modelled labour market changes in road transport focusing on drivers, but also other workers in road transport. The models show that road transport employment will decrease with CAD, mainly due to freight services, where there is a sharp drop in driver employment. Job growth in manufacturing, IT and steward services for passenger transport (ride sharing, robo-bus) can only partially make up for the decrease in employment. He also showed that ambitious CAD deployment is stimulating economic growth.

You can watch the full presentation by following this link: https://youtu.be/I2dQ_b592K0?t=1225

Presentation 2: External perspective on expectations and concerns of CAD

Amandine Duboz (JRC) presented the special Eurobarometer 496, which showed expectations and concerns on CAD, based on the opinions of more than 27,000 citizens across the EU. The survey explored previous knowledge, attitudes, mobility needs, expectations, concerns and policy implications. She also presented on the CAD living labs that are being set up on the JRC's premises in Italy and the Netherlands. They are meant to engage citizens in innovating mobility solutions, increase public engagement in policy, analyse articles and organise focus groups.

Her full presentation can be viewed following this link: https://youtu.be/I2dQ_b592K0?t=2790

Q&A on the labour market impacts

Stephane Dreher (ERTICO ITS-Europe) opened the floor for attendees to ask questions:

Questions and answers
• For the employment study, was there an assumption that the volume of traffic remains the same? - Wolfgang Schade: No, the model does not assume constant traffic volumes over time, but it is evolving according to the growth trend in the EU reference scenario. This is also the reason why we see a growth in transport service employment until 2035.
• What about the age distribution of drivers, will the job loss be solved by ageing and retirement? - Wolfgang Schade: The age distribution of drivers was not directly tackled in the modelling, as this is part of the social impacts (next presentation). However, of course we are aware of the difficult situation in especially the freight transport sector, where we see a growth in employment demand over the next 10 years, while they have an issue with ageing of drivers and need to attract more young and female drivers in the short to medium term with the expectation in mind that CAD might affect the profession.
• Is transport limited by the number of drivers? - Wolfgang Schade: Yes, it is limited due to the age profile and the sector must make efforts to attract younger drivers and make sure they have the necessary skills for the later transition to CAD.
• You expect a stable large conventional bus share in all scenarios. How certain are you? Other studies suggest replacement of most conventional busses by robo-shuttles, at least in some scenarios? Will people make a long journey to a conventional bus stop if a shorter waiting time is possible with robo-taxis? - Wolfgang Schade: The scenarios are driven by cost and time variables, the outcome of using this variables is that conventional buses will lose some shares but not all. There are capacity problems in urban areas and we cannot shift easily from one huge bus to 10 or 15 smaller vehicles. This is maybe possible in rural areas and suburbs, where large busses are inefficient and smaller vehicles and on-demand vehicles are more likely.
• You mentioned about the necessity of changing profession (e.g. IT services, supervision). But in practice, not many drivers will be able to change their job or employment sector.

Questions and answers
- Wolfgang Schade: This corresponds more to a change of job within the transport sector, not a change of sector. Drivers can move into the area of supervision or steward at bus stations. The workforce employed after 2030 will have a new skill set and likely requires more IT knowledge.
• How can living labs be used to also study social impacts in employment and for testing policy solutions? - Amandine Duboz: Regarding employment, this is not the aim of living labs for now. But, more general about the social impact, we will test automated vehicles on the JRC site and for us this is really an opportunity to learn people's opinions on such vehicles. The JRC site is a closed environment with few roads, providing a perfect surrounding to test automated vehicles and to learn how passengers react to it and how they would like to use them. This allows us to better understand the impact on citizens and thereby to elaborate better policies.

Link to the Q&A: https://youtu.be/I2dQ_b592K0?t=3710

Presentation 3: Presentation of the social impacts of CAD

Nils Verkennis (Ecorys) presented the social impacts of CAD such as changing skill requirements, impacts on professional and socio-economic characteristics and cross-cutting issues. He highlighted how CAD (up until level 4) will impact skills by introducing a shift from manoeuvring vehicles to supervising automation systems and monitoring the environment. He also outlined that the average age distribution in road transport is expected to increase, and that in the short term CAD is not going to alleviate this problem. In the long term, automation will likely make the sector more appealing to a younger workforce. CAD is not going to be the solution for a more gender balanced sector, additional efforts are needed here. Finally income levels could rise due to higher skill requirements. He ended his presentation by stating that while in the short-term CAD is not going to solve the problem of driver shortages, it has the potential to improve social inclusion in the profession and in wider society.

For the full presentation, please click here: https://youtu.be/I2dQ_b592K0?t=4365

Presentation 4: External perspective on social impacts of CAD

Evangelos Bekiaris (CERTH-HIT) presented the that automation might polarise jobs with robots requiring high skills to be designed and built, but low skills to be operated. Therefore, there is the risk of an increasing income gap. However, if AI matures, then also intellectual non-routine tasks can become automated leading to convergence to the middle skill spectrum. There are also differences across countries regarding the readiness for automation in transport. Some EU Member States consider that there is a lack of skills to face automation. However, it is likely that there will be sufficient time for the labour market to adapt as automation is not revolutionary but evolutionary. He then presented on the SKILLFUL project, which developed 28 priority schemes and scenarios on skills and competences that will be needed due to automation and create new job opportunities.

The full presentation can be accessed here: https://youtu.be/I2dQ_b592K0?t=5475

Q&A on the social impacts

The second discussion was opened by **Geert Smit** (Ecorys) asking two polls to the audience:

1. How do you think will the introduction of CAD affect freight and passenger transport?	2. Will CAD deployment lead to a more diverse workforce in the road transport sector?
64% - More jobs will be lost in freight transport. 9% - More jobs will be lost in passenger transport. 24% - Both will be affected equally. 3% - I do not know.	76% - Yes, more diverse workforce, including female workers. 15% - No. It will lead to a less diverse workforce. 9% - No. The situation will remain the same. 0% - I do not know.

Thereafter, the floor was opened to questions to the speakers:

Questions and answers
• How can CAD make transport more accessible to low income people? - Nils Verkennis and Wolfgang Schade: CAD vehicles will be more expensive because they contain more technology. However, the faster the roll-out of automated vehicles the more likely manufacturers will provide low-cost alternatives. In addition, shared services could possibly help. However, it all depends on the implementation as implementing more shared services in remote areas may impede low cost mobility. The more you bundle the better the cost savings and finally, not having a driver in the car is of course also a reduced cost.
• In the 4 scenarios there is no real sustainable scenario focussing on fast uptake of driverless public transport and high increase in public transport and increase in rail transport. Driverless public transport will not be totally "humanless" but will be on demand, cheaper and more comfortable, so that people do not need their cars anymore. - Wolfgang Schade: This is on purpose as we were not looking for the most sustainable scenario, but to isolate the impact of CAD. If we would think about the more sustainable scenarios we would have included a stronger emphasis on other factors such as electromobility, modal shift to rail, and others.
• Could you elaborate on why the difference between freight and passenger transport is that considerable. - Wolfgang Schade: The difference lies in how we see passenger and freight reacting to the introduction of CAD. In freight, automation starts already with SAE level 4, while in passenger transport we expect to see this only with level 5, as only then robo-shuttles and robo-taxis would be able to operate autonomously. The other reason is that there are more compensating jobs in passenger transport such as stewards and mobility operators than in freight. - Evangelos Bekiaris: We should also not forget the mixed use with some vehicles acting as passenger transport throughout the day and freight at night or even at the same time with separate compartments. In addition, today a major barrier people today is security, not safety. Passengers want to see someone in the car. Therefore, it is more of a temporal issue with first autonomous driving appearing in logistics but eventually with people seeing freight applications as successful, then we consequently should see a shift for passengers too.
• Could you further explain the skill differences between drivers and mobility operators? - Nils Verkennis: The driver is actively steering the vehicle, while the mobility operator is in a monitoring and supervision role regarding the system and the environment. The operator needs also be ready to take over steering in case of emergencies.
• It does not seem reasonable to extrapolate the introduction of platform stewards instead of drivers on Metro platforms to the same introduction on bus platforms. The extra created value is far lower, thus this evolution cannot be taken for granted. - Wolfgang Schade: A very good question. The shift to stewards should not be seen as a radical break but an evolutionary transition. Over time, we will see different approaches depending on the level of technology with stewards being introduced on some bus platforms. This differs also regional, where in some regions the responsible authorities or operators might decide to work with stewards. - Laura Babío: It is very important to keep a social reality in mind, because at the end the whole rational of having automation is to save the costs of the driver, so you can use it in areas where public transport otherwise was not cost-effective. So if you introduce the stewards this would defeat that purpose. Perhaps there would be a compensation in jobs in public transport, but still it needs to be seen if this can be through stewards, instead compensation could maybe come through infrastructure maintenance.
• The goal of automation is also to increase road safety, it is good to keep in mind that benefits go beyond just social impacts. - Geert Smit: Yes indeed, this study focused on social impacts, but it is good to note of the fact that benefits go beyond the social impacts.

Link to the Q&A: https://youtu.be/I2dQ_b592K0?t=6747

Presentation 5: Meeting societal needs in an evolving CAD landscape

Stephane Dreher (ERTICO ITS-Europe) presented an overview of what has been the focus of R&I, pilot activities, and roadmaps on CAD so far in Europe. He summarised the results of an analysis done in the frame of the EU-funded CARTRE Support Action which studied the main scope of about 50 roadmaps and about 80 pilots/test sites from around the globe. The study did show that so far studies on societal aspects and impacts have been underrepresented. The public knowledge base website[59] developed in the follow up EU funded project ARCADE provides an overview of studies and pilot activities split by sub-topics. The mapping of more than 200 initiatives shows that the focus on societal aspects has increased through more EU funded projects and in particular more regional or local trials with shuttles looking into user acceptance on societal impacts.

His full presentation can be watched here: https://youtu.be/I2dQ_b592K0?t=7753

Afternoon session on policy recommendations in key policy areas[60]

Introduction: Toward a social roadmap for CAD

Geert Smit (Ecorys) opened the second part of the conference with a recap of the morning session. He pointed out the loss in demand for jobs and the importance of defining policy options to deal with the identified impacts, as well to work towards developing a social roadmap for CAD. He also presented the conceptual framework of the study working from impacts, over opportunities and challenges towards policy recommendations.

Presentation 1: Policy options for the short, medium and long-term

Michael Flickenschild (Ecorys) explained in his presentation that the main goals of the policy options are to jointly prepare for, facilitate and manage the transition. He presented various social challenges and opportunities such as imbalances in labour demand and supply, change in skill requirements, the chance to improve work conditions, the risk of social strive due to displaced workers, and contextual challenges such as climate change. He then presented a phased approach to address these, including preparation in the **short term** until 2025, by for example setting up a network of living labs and initiating targeted studies. Thereafter, in order to facilitate the transition in the **medium term** until 2035, policy measures could include working towards a joint transition strategy and reviewing and adapting relevant social legislation. Finally there is the need to manage the transitional effects in the **long term** by monitoring employment and social impacts through an observatory and supporting regions affected by transition.

His full presentation can be viewed here: https://youtu.be/I2dQ_b592K0?t=9140

Presentation 2: Future R&I needs and CCAM Partnership perspective

Ingrid Skogsmo (VTI) presented the CCAM (Cooperative, Connected and Automated Mobility) partnership, which aims to contribute in making transport safer, greener and more accessible. The partnership's vision is to provide benefits to all citizens through safety, a sustainable environment, inclusiveness, and competitiveness. The CCAM Partnership involves a multifaceted stakeholder community including industry, research, regulatory bodies, representative bodies, mobility and logistic services and public authorities and road operators. It sets out a strategic research and innovation agenda and the heart of it are large-scale demonstrations, but also societal aspects and user needs.

You can watch her full presentation here: https://youtu.be/I2dQ_b592K0?t=10335

59 https://knowledge-base.connectedautomateddriving.eu/.

60 Start of the afternoon session: https://youtu.be/I2dQ_b592K0?t=8658.

Q&A on policy options for road transport

Stephane Dreher (ERTICO ITS-Europe) opened the floor for questions to the speakers:

Questions and answers
• It is important indeed that we look at the broader picture considering the full value chain. Now in actions that are developed under CCAM, is the priority to further research and understand the impacts or is it more about coordination that all the actors in the value chain are included in this discussion? - Ingrid Skogsmo: You are right, it will be critical that all stakeholders are involved that could have a say in this. It has been a technology push for a while, but ideally there could also be a pull for CCAM, which may require tools or methods in addition to dialogue such as collaboration and cocreation.
• As long as we talk about private cars and normal people being todays drivers the transition will be made without additional learning. The economic aspects will lead to driverless vehicles and there will only be stewards needed to ensure safety, so why do you expect new skills for drivers? - Michael Flickenschild: Yes that is correct, however this will be a gradual process and there will be a process where professional drivers need to adapt to new skills and adapt to changing situations. But it is true, the moment will come when drivers will not be needed anymore and then we need to consider measures to retrain them and find new occupations. This transition was shown also in Wolfgang Schade's presentation on the impact on freight driver employment. - Ingrid Skogsmo: This is maybe public transport that you refer to, but for professional drivers in freight transport obviously the idea is that they could do a lot of other task while they are in automated vehicles. So there may be new skills that need to be developed, but also there is the need to maintain skills that become less important but need to be maintained for critical situations.
• How do you see the evolution and coordination of living labs across Europe? - Michael Flickenschild: Indeed there might be some lagging regions. We have not looked into details into this, but one solution could be for the European Commission to be vigilant in providing funding also to lagging Member States so they can take part in the process. However, quite naturally this is something that will happen at different pace across the EU. Living labs should be for all. - Ingrid Skogsmo: One of the big things that we want to emphasise in our societal needs cluster that this has to be for all. There has to be equity and within that lies that while some regions may have to be first, we need to develop something that can be applicable to all of Europe. This is a process and learn by doing is a good idea as is enshrined by the living labs approach.
• How do we train drivers with new technologies and how do we upskill now in preparation and how do we encourage more men and women to join the profession? - Michael Flickenschild: Certain aspects were mentioned in my presentation, but to elaborate we see the need to update curricula to train drivers for the future. Specifically, with the already existing periodic trainings, drivers could gradually pick up more knowledge when shifting to automation. Policy measures are also needed, such as targeting men and women in awareness campaigns, but also the improvement of work conditions such as raising salaries across Europe in order to make the sector more attractive. The hope is that CAD can help with that, however flanking policies are needed such as the new Mobility Package improving some of the rules for drivers.

Link to the Q&A: https://youtu.be/I2dQ_b592K0?t=11445

Panel discussion: Reflections from sector stakeholders on a social roadmap for CAD[61]

The final part of the conference, the panel discussion, was opened by **Geert Smit** (Ecorys). He introduced the six panellist, who represented freight transport, passenger transport, manufacturing, cities and users, and transport workers. Each panellist was given an opening question on *what they see as the major challenges caused by the introduction of CAD:*

Johanna Tzanidaki (ERTICO ITS-Europe) joined the panel as part of ERTICO which represents a broad selection of stakeholders including research, OEMs, service providers,

[61] For watching the panel discussion, click here: https://youtu.be/I2dQ_b592K0?t=12170.

ministries, and cities all brought together by the topic of innovation. All these partners know that innovation does not happen in isolation. The major challenge caused by the introduction of CAD is the lack of understanding and awareness on what is coming and on the inevitability of it. If we do not understand this, then we do not come together to cooperate. As said by Frank Smit this morning, the system has emerged by design and as a result of crisis management. We have to prepare, as is also put forward by the study. Therefore, in order to overcome the lack of understanding and awareness we have to cooperate between stakeholders, competitors, users, and also other unfamiliar partners in this ecosystem.

Inga-Lena Heinisch (ETF) introduced ETF, which is representing more than five million transport workers across Europe and is a recognised social partner in seven of the social dialogue committees. Automation is an important topic for ETF and there are three major issues they focus on in light of this. First, driver shortage and the misconception that driving is not a skilled profession. The precarious work life balance in this job makes this profession not very attractive leading to an ageing profession and a lack of women participation. Many Member States do not consider this profession as skilled, which downgrades the job. Any innovation can be a step forward here. Second, the unattractiveness of the sector, which was discussed in several of the panels. However, the discussion does not really address what female workers are concerned about. The five main issues raised are a toxic masculinity at the workplace, unequal pay and unequal opportunities, violence by colleagues or customers, lack of work life balance, and lack of sanitary facilities for women. We do not see that automation will attack more women and young people to the profession as long as these more fundamental issues are not addressed. The third challenge is driving time, in our view drivers are paid related to working time and not driving time. So platooning is not saving on labour costs as it should not change how drivers are paid. ETF is currently conducting a study investigating driver fatigue in this regard.

Brigitte Ollier (UITP) works for UITP, which represents public transport companies enabling mobility of citizens across Europe. It is difficult to single out the effects of CAD as it is not really deployed in their networks yet. There are some pilots running, but automated road vehicles are very marginal in everyday services. The sector provides for approximately 2 million jobs in Europe, only 18% are held by women. This is an issue our members are very aware of and activities have been developed to attract more women, but they are not very successful, due to reasons such as those mentioned by Inga-Lena Heinisch. Over 50% of the jobs are driving jobs. There is an ageing workforce and some companies expect up to 30% of their staff retiring in the next 10 years. Considering current policies such as the European Green Deal cities will need even more public transport services to keep up with the demand. Thus for the next 10 years, recruiting drivers and other workers will be the challenge number one. It is also very important that diversity needs to be increased by recruiting more women. Moreover, with the digital transformation jobs and skills are changing (e.g. e-ticketing), and we have to accompany change. Recruiting new skills is not enough, therefore as a second challenge we need to also re-skill or up-skill current staff to address these changes. It is very important to have cooperation, to address fears of staff, and to keep up discussion to explain and jointly address the changes.

Laura Babío (POLIS) represents POLIS on the panel, which is a network of cities working on sustainable transport innovation. Automated vehicles do not necessarily lead to an improved social situation, while there are many benefits associated such as increased accessibility for certain citizens and in low-demand areas, there are also risks including traffic congestion and inequality depending on the business models. The biggest challenge for cities would be to integrate autonomous vehicles in their current transport system while making use of the advantages but carefully managing the integration so that sustainable objectives are met while minimising the risks. In the end, cities are not interested in automation per se, but how it can solve particular problems.

Automation requires huge investments and this is only justified if it can lead to social and environmental improvements.

Carlo Giro (IRU) works for IRU, representing the commercial road freight and passenger transport sector including taxis. IRU acknowledges that automated driving has the potential and capability to revolutionise road transport by making transport operations more efficient and attracting a new workforce. However, this cannot come without targeted policies. There are two major issues. The first one is related to acceptability. Many pilots are taking place, but there are no concrete solutions on the road right now and many members are still unaware of what is going on. It is also the responsibility of IRU and other organisations present to improve awareness and acceptance. The second one is the role of SMEs. Approximately 80% of transport companies in the EU are SMEs. They should not be left behind and instead facilitating measures should be developed to help them during this transition. Moreover, there is the need for training, upskilling, and retaining drivers. The sector is competitive and CAD might work for a private user, but there have to be some business needs that have to be addressed which concern the commercial road transport sector.

Joost Vantomme (ACEA) is the Smart Mobility Director at ACEA representing the vehicle manufacturing sector, which includes 13.8 million workers in Europe. The main attention point for ACEA and for the driver is safety and not only the vehicle safety but also the safety of the system and the interaction with third parties. It is about trust, ACEA is coordinating with the European Commission the trust programme for the common data spaces. When things go wrong, it will be very difficult to remedy later. Therefore, it is important to focus on safety to increase trust but also transparency of the systems (i.e. what is an automated system, what can it do). ACEA developed a roadmap on automated driving, which includes also a taxonomy on automated driving in order to have the right terminology in place. For example, the distinction between assisted driving, automated driving (first steps of automation) and autonomous driving (machine is driving and not you). There are already some use cases in place such as automated parking, but others such as robo-taxis will come too. It is a multimodal issue and therefore ACEA discusses each ecosystem and its needs with relevant stakeholders (e.g. IRU, UITP, POLIS). It is about how to produce cars for a changing and new ecosystem. Third factors such as Covid-19 are also affecting these developments such as causing a massive reorganisation in companies, unpredictability of the future, and structural changes.

After this first round of interventions, **Stephane Dreher** (ERTICO ITS-Europe) asked panellists to *reflect on the policy measures mentioned during the presentations and how they see the roles of different stakeholders:*

Laura Babío (POLIS) the roadmap of policy measures developed is very interesting. There are some that are key to cities, the main one is limiting traffic growth by posing restrictions and promoting public transport. Another very interesting one is to provide funding for the transition based on a transition strategy, however this has to be linked to specific problems. For example, rural areas do not currently have public transport because it is not cost effective, so automation could help a lot there. Finally, establishing a framework agreement on automation for road transport and the cooperation and dialogue this entails would be beneficial too.

Inga-Lena Heinisch (ETF) agreed with the previous speaker and added that the report covers a lot of topics ETF is also concerned about. The main three topics for ETF are that the impact on jobs and employment must be included in the social dialogue at all levels and more in depth and not just the European level. Drivers see that things are changing but they are concerned for their day to day job. Secondly, there is a need to adapt the training of drivers directive, since upskilling and retraining are key and redesigning the curriculum is important also signalling that the driver profession is a skilled one, ensuring better pay and work conditions. Lastly, ETF also calls for EU research funding is allocated to study the social impacts.

Johanna Tzanidaki (ERTICO ITS-Europe) mentioned that CAD is not coming but already almost with us, so we need to be fast in understanding and accepting it. We need to see the full picture while continuously working in parallel on different parts of the puzzle. In the beginning there will be mixed traffic, probably with separate lanes, then we may have people losing their jobs and getting frustrated. However, we can plan for this and mitigate by training, starting in schools, or sharing information with public authorities. The ERTICO academy[62] is sharing actively the knowledge on traffic management and the impacts of automation with public authorities. It is important to work on different policy levels and go beyond the EU level when sharing the relevant information. It will be important to take into account various needs when developing solutions and indeed cities do not care about automation, they rightfully care about what automation can do for them.

Joost Vantomme (ACEA) mentioned that a few years ago the whole connectivity agenda was not yet visible. Now it has become part of the agenda and it is rolling out. Communication across sectors such as vehicle manufacturing and communication technologies is an important aspect. ACEA together with CLEPA and other organisation developed an action plan for a successful restart of the EU's automotive sector after Covid-19. Two of the 25 actions are linked to an updated skills agenda. First, there is the need for a sectoral skills pact within the automotive sector and also mobilising private capital. They leveraged the existing ERASMUS+ platform to set up the DRIVES project which looks into future skill needs in the sector. This project is now delivering a roadmap and drafting job profiles. They are looking for a multiplier effect where we can mutually recognise the definition of skills, map the needs of the industry and promote cooperation with regional and national authorities. It is important that this preparation starts now and that we are ambitious.

Brigitte Ollier (UITP) added to the discussion that one needs to make sure to not be pushed by technology into things that will not add value for customers. Speed of deployment depends on the real added value for users. Smaller vehicles could connect in a more efficient way areas that are currently not well connected. However, mass transit and big busses will still need large vehicles for peak times. It is unclear at what speed these vehicles can be automated. Passengers might not feel very comfortable in such vehicles, therefore it will be important to keep a human presence in these vehicles as has been done for Metros. On the aspect of skills, we have to make a big effort from the side of public transport to re-skill and up-skill so workers can cope and not only in the automated area but in digitalisation in general. Some business processes are being digitalised already and we need to better understand the impact of new business models.

Carlo Giro (IRU) voiced his support about the need to revise social legislation in road transport, because there need to be clear rules that transport companies need to abide to. In addition, living labs could represent a good starting point for stakeholders and user groups to assess CAD and how it reflects their needs. Currently, most of the time pilot activities do not include all stakeholders and IRU's members would be keen to be included in these living labs or pilots. A gradual introduction that includes real users and real transport providers would represent a constructive approach. Finally, in general terms, Covid-19 has highlighted the need to digitalise the road transport sector.

After this second round of responses, **Geert Smit** (Ecorys) asked panellist for *their closing remarks:*

[62] https://ertico.com/academy/.

In his concluding remarks **Joost Vantomme** (ACEA) stressed the need for a systematic and systemic approach through a public-private partnership that includes a sectoral skills pact. **Brigitte Ollier** (UITP) highlighted the need to reinforce social dialogue. Already, closer cooperation between employees and companies has been established during Covid-19, which should be further enforced and deepened and lessons-learnt should be applied also for the emerging digital transformation. **Carlo Giro** (IRU) flagged that a European Commission report from 2019 forecasted passenger and freight transport passengers to grow significantly by 42% and 60% respectively by 2050, putting further pressure on the transport network. It is the responsibility of all relevant stakeholders to tackle the demand. Furthermore, the upskilling and reskilling of drivers as well as the transfer of knowledge needs to be processed in the right direction. **Laura Babío** (POLIS) underlined that we should not be pushed by technology and encouraged that expectations of automated vehicles need to meet social values and needs. **Inga-Lena Heinisch** (ETF) added that any projects in regard of CAD need to be human centred and need to meet the needs of workers and users. It is also key that any changes through innovation or otherwise should not be used to circumvent labour laws. Finally, **Johanna Tzanidaki** (ERTICO ITS-Europe) closed by voicing her appreciation of cooperation and dialogue being one of the main themes throughout the conference as both are required to establish acceptance and make the benefits of CAD visible to everyone. All projects should be user centred, because no one can cooperate unless the benefits are clear for everyone and unless the technology adds value in addressing social and environmental challenges.

Geert Smit (Ecorys) in thanking panellists for their contributions voiced his appreciation for the panellists bringing their different views together as this can serve as a first step towards working together on a social roadmap for CAD. He then thanked all speakers, the attendees, ERTICO for hosting the meeting, and the European Commission for commissioning the study. **Stephane Dreher** (ERTICO ITS-Europe) echoed Geert Smit's words by also thanking everyone involved and saying that he looks forward to future collaboration on the topic. After these closing remarks, the conference was closed.

The full recording can be access here: https://www.youtube.com/watch?v=I2dQ_b592K0.
For questions please reach out to: CAD.employment@ecorys.com.

Annex H – Impacts on business models

The study included an analysis of the impact of CAD on development of innovative business models and operating models. The main focus was on business models which have potential to affect the market of transport and markets of other goods and services and therefore having an impact on industry and society.

An overview of the approach used in the analysis is presented in Figure I.1. The work was started by identifying the main business cases enabled by CAD. These business cases were then described as value networks with an appropriate level of detail. After the value network had been described, it was possible to identify the key stakeholders in the business case. When identifying the key stakeholders, the first task was to identify the focal company that is likely to have market power and to exercise control over other stakeholders in the supply chain described as value network. In addition, the stakeholder that owns an automated vehicle in each of the business cases was identified as a key stakeholder, as it has control over the vehicles, will likely earn revenue from their use and will incur expenses for operating the vehicles and investing in them. As a result of these steps, the first part of the analysis provided the business model of the focal company or other key stakeholder in each of the analysed business cases as well as other characteristics of the business case (value network, key stakeholders).

The business cases related to CAD analysed during the work are listed in Table H.1 These were developed on the basis of a brief literature study and the results of the first and second round of stakeholder consultation carried out in the project.

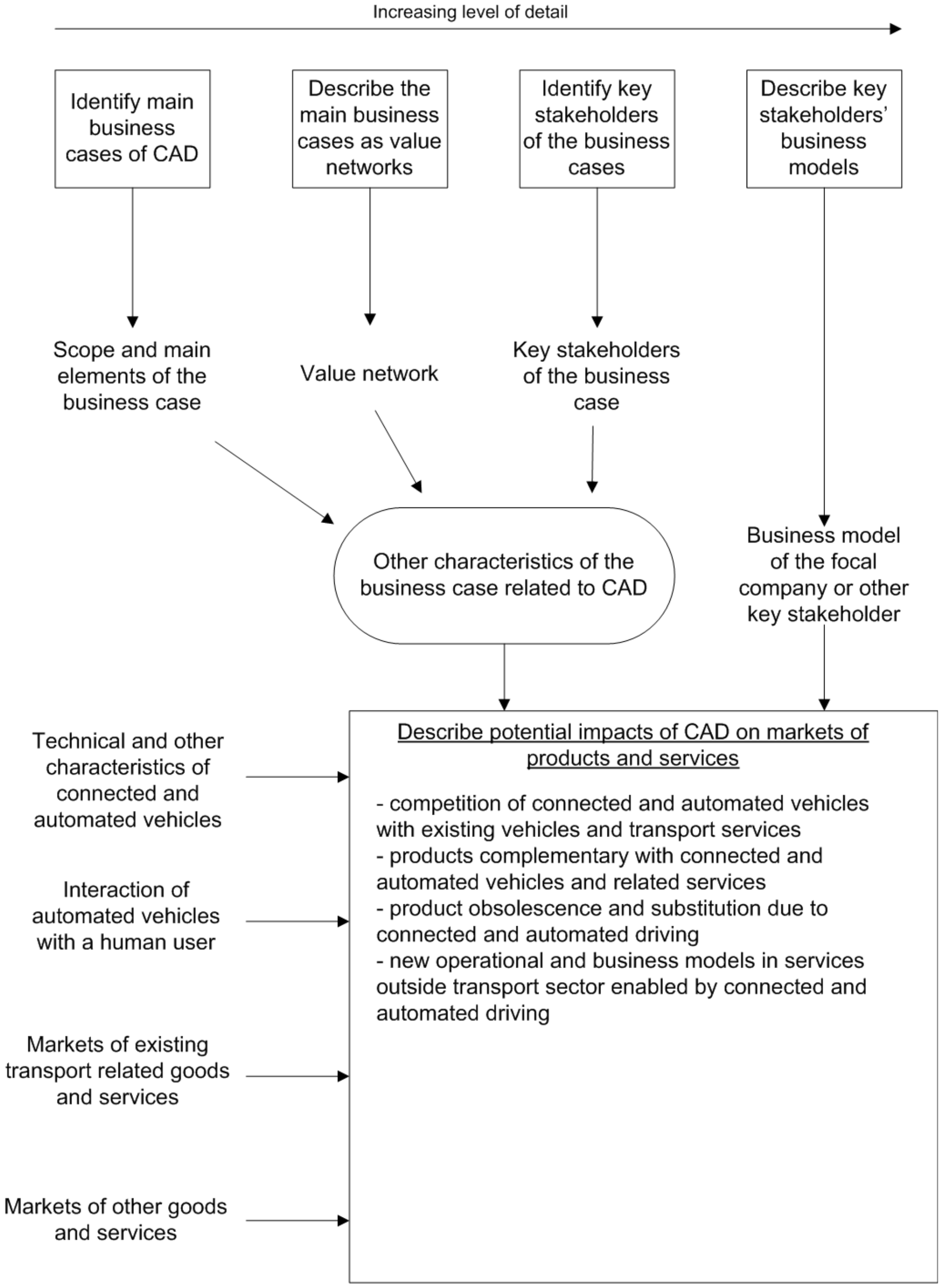
Table H.1 Main business cases related to CAD.

Business cases		Business case characteristics			
Number	Name of business case	Vehicle owner	Focal company	Relevant sources	Comments
B1	Highly automated vehicle as a robotaxi	Robotaxi operator, affiliated with automated vehicle manufacturer	Automated vehicle manufacturer	[1, 2]	Trials going on
B2	Automated shuttle providing a local public transport service	Automated shuttle operator	Automated shuttle operator, public transport authority	[3]	Trials going on
B3	Long-haul goods transport with a highly automated vehicle	Automated truck operator, affiliated with automated truck manufacturer	Automated truck manufacturer, integrated logistics company	[4, 5]	Under development, most likely to appear first between logistics hubs such as harbours and cargo terminals

Business cases		Business case characteristics			
B4	Local goods delivery with an automated vehicle	Automated vehicle operator, affiliated with automated vehicle manufacturer	E-commerce platform or consignor	[6]	Starting trials [6-8], e.g. groceries or pizza delivery in local community by a robot or a light highly automated vehicle
B5	Privately owned highly automated vehicle	Private car user	Automated vehicle manufacturer	[9]	Under development but not on the market yet, corresponds to the current paradigm and culture of vehicle ownership

The business model of one key stakeholder was described for business cases B1-B5 described in Table H.1. The tools used for describing key stakeholders' business models included value network [10, 11] and service business model canvas [12]. When the value networks of different business cases had been described, key stakeholders had been identified and key stakeholders' likely business models had been described, it was possible to describe the anticipated impacts of CAD on the markets of products and services (Figure H.1).

Figure H.1 Overview of the analysis approach.



Description of new or different business models

B1, Highly automated vehicle as a robotaxi, description of the business case

In business case B1, a highly automated vehicle is operated as a robotaxi. Field tests of driverless taxis are already going on [1, 2], although the technology used is still under development. The value network of the robotaxi service provided in the business case B1 is provided in Figure H.2. Like in business cases B2–B5, the manufacturer of automated vehicles is likely to have a network of Tier 1 and Tier 2 suppliers which provide components and subsystems used in automated vehicles. In the trials carried out so far, the automated vehicle has had ownership in the company operating the robotaxis, or the robotaxi operator has been closely cooperating with the manufacturer of automated vehicles.

In practice, the relationship between the automated vehicle manufacturer and the robotaxi operator may take many forms. First, they may be consisting of a single company, be part of the same group of companies or the robotaxi operator may be otherwise controlled by the vehicle manufacturer (hierarchical or captive value chain, see [13]). In this case, they will together form a focal company having substantial control over suppliers and at least some market power. In the long term, the relationship between automated vehicle manufacturer and the robotaxi operator will probably evolve towards relational value chain (in which “buyers and suppliers engage in complex interactions” creating “mutual dependence and asset specificity” [13]) or a relation of a buyer and a turn-key supplier. When new technology becomes more mature, the buyer and supplier will be better able to express their request as written contracts (to “codify their requests”), transactions will become less complex and supplier capabilities are likely to increase. These three factors are likely to facilitate development of supply chains from hierarchical and captive supply chains towards relational and modular supply chains [13].

The robotaxi operator will be a new entrant on the existing market of taxi services. When entering the market, it will face competition with other taxi operators. On the other hand, entering the market of taxi service is subject to restrictions in many countries (e.g. the number of licensed taxi vehicles in a given geographical area may be limited), and these restrictions may prevent the robotaxi operator from entering the market. In addition to the participating in the market of taxi services, the robotaxi operator has also other opportunities for realising revenue. These include e.g. partnering with an airline or rail transport operator to provide a door-to-door journeys to rail or airline passengers. In addition, the robotaxi operator may establish collaboration with a MaaS (mobility as a service) platform.

Figure H.2 B1, Highly automated vehicle as a robotaxi – value network

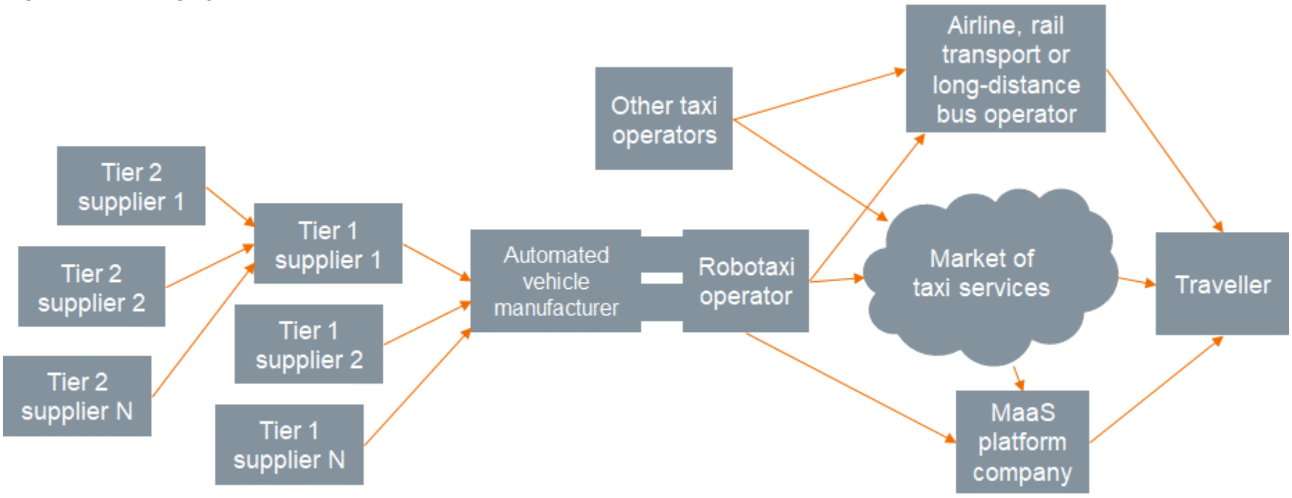


Table H.2 describes the business model of the robo-taxi operator as a service business model canvas. The text in cells in the middle row explain the cost structure, key resources, key activities, value proposition of the focal company as well as the contribution of the focal company to maintain the relationship, channels provided by the focal company and revenues received by the focal company. Corresponding items are described for the customer on top of the row representing the focal company and for supplier or suppliers under the row representing the focal company. The customers in the business model and the key partners of the focal company are described on the top and bottom rows of the table.

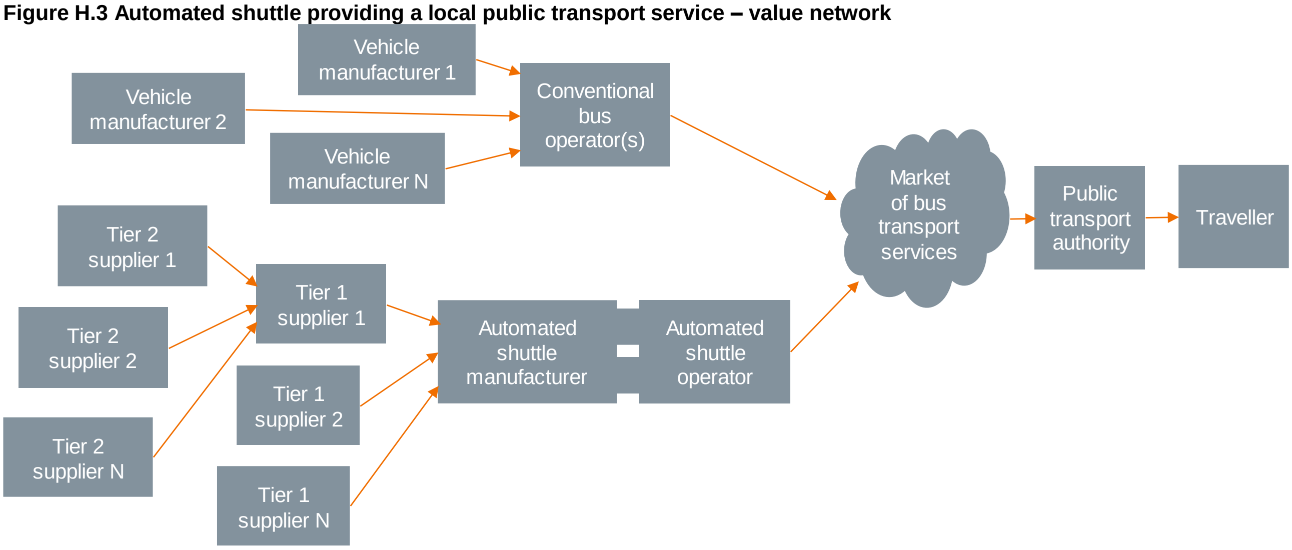
Table H.2 The business model of the robotaxi operator, business case B1: highly automated vehicle as a robotaxi

	Customer (traveller)						
Customer perspective	Taxi fare, may be based on kilometres travelled, time or a fixed price	Smartphone or other device with an internet connection (for booking the service), means of payment (e.g. credit card or online banking credentials)	Booking of service and payment using an online system and their own terminals, travel in robotaxi, feedback to service provider	Taxi ride with more affordable price, increased availability and with no need to interact with a human driver	Registration to the service platform, receiving marketing offers online and offline	Smartphone, laptop, desktop computer, for booking, payment and other use of one or more service platforms	No revenues typically captured by customers
Company perspective	Cost structure Investment cost (automated vehicles and a service platform), operating costs of vehicles (including: monitoring and operations, repairs and maintenance, cleaning, security), marketing and operating costs of a service platform, insurance (if not provided by vehicle manufacturer)	Key resources Fleet of autonomous taxi vehicles, service platform with booking, payment and feedback features, licence to operate a taxi service in a defined geographical area	Key activities Operation of fleet of autonomous taxis, operation of service platform, collaboration with automated vehicle manufacturer	Value proposition Taxi service produced with lower variable costs related to operating or standby time and implemented with a fleet of robotaxis, creating a sales opportunity and a potential data source for manufacturers of automated vehicles	Relationship Robotaxi operator provides a service platform with booking, payment and feedback features and markets it services online and offline. Robotaxi operator may also collaborate with MaaS platforms, airlines or rail transport operators with direct relationship with the traveller.	Channels Service platform of the taxi operator available to travellers, MaaS platforms and online service platforms of other transport companies (e.g. airlines or rail transport operators) integrated with the robotaxi operator and related interfaces	Revenue streams Taxi fares paid by travellers, revenues from services provided to MaaS platform companies, revenues from services marketed and paid via airline or rail transport company web sites, revenue from advertising, revenue from data collected by robotaxis
Partner perspective	Costs of developing highly automated vehicles used as taxis, liability costs, costs of implementation of a service platform or integration with a robotaxi operator	Knowledge and IPR required for manufacturing automated vehicles, type-approved vehicle models, research and development resources suitable for the task, vehicle manufacturing capabilities or collaborative relationship with a vehicle manufacturer, online service platform for marketing robotaxi service	Development of highly automated vehicles, vehicle manufacturing, marketing of robotaxi service via online service platform	Creates a market for autonomous vehicles as taxis and creates a fleet which may act as a data source in development of CAD.	Marketing of robotaxi service as a complementary product (e.g. rail or air ticket) or a part of the offering of a MaaS platform	Interface to a MaaS platform or other online service platform (e.g. airline or rail operator)	Revenue from sales or leasing of automated vehicles, revenue from users of a MaaS platform, revenues from users of partner web sites (e.g. airline or rail company)
	Key partners (automated vehicle manufacturer, MaaS platform, other online service platforms such as rail operators or airlines)						

B2, Automated shuttle providing a local public transport service

In business case B2, an automated vehicle is used to provide a local public transport service. It is assumed that this corresponds to operation of an urban or suburban bus line with an automated vehicle. The value network related to the business case is described in Figure H.3.

Figure H.3 Automated shuttle providing a local public transport service – value network



The relationship between the automated shuttle manufacturer is likely to be similar to the relationship between automated vehicle manufacturer and the robotaxi operator described in business case B1. The automated shuttle operator will be a new entrant in the market of urban public transport services. Alternatively, an existing bus operator may establish collaboration with an automated shuttle manufacturer to provide line-based public transport with automated shuttles. Most relevant competitors of the automated shuttle operator will be conventional bus operators. In many cities, the market of bus services has only one major buyer – the local public transport authority which manages the ticketing system of public transport used in the region or city and sells tickets to travellers. Transport authorities responsible for public transport need to comply with legislation on public procurement. In most cases, the selection of a bus operator is to large extent based on the offered price. The business model of the automated shuttle operator is described in Table H.3.

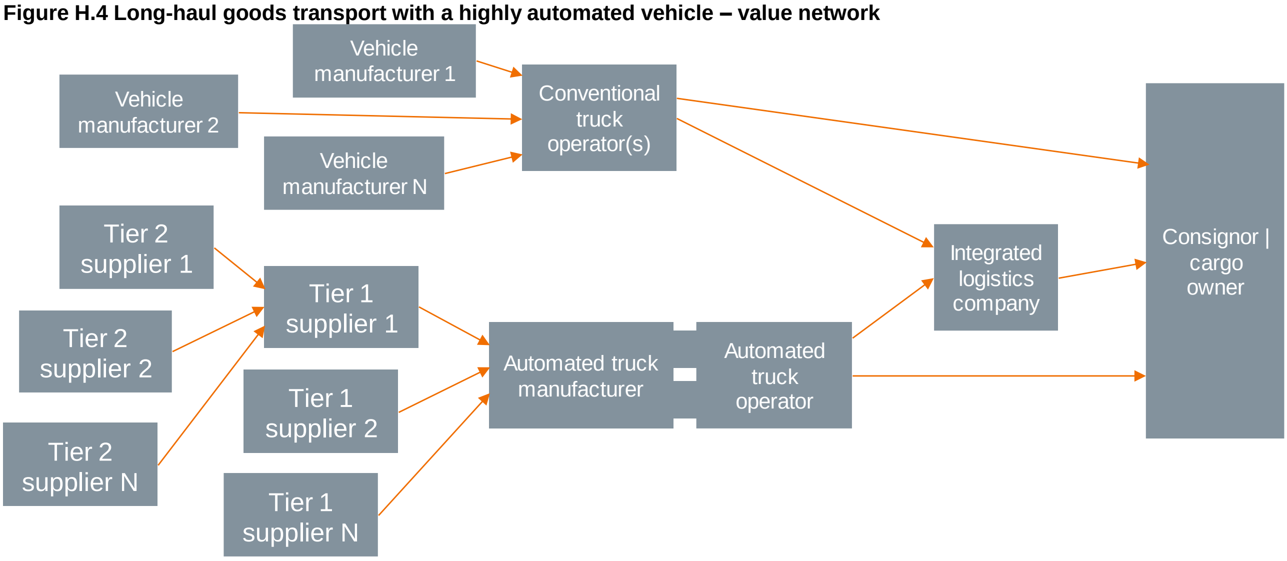
Table H.3 The business model of the automated shuttle operator, business case B2: Automated shuttle providing a local public transport service.

Customer perspective	Customer (public transport authority)						
	Fixed price agreed in a contract on operation of public transport services, may be based on performance and quality indicators of the service	Public transport planning functions, ticketing system, traveller information systems	Public transport planning, management of ticketing system, ticket inspection, providing static and real-time traveller information	Increased coverage of public transport service or maintaining the same service level with lower operating costs (e.g. periods of low demand, areas of low density, areas not accessible to city buses or private cars).	Planning of publc transport service to be provided with automated shuttles, defining quality requirements for the service, contract management and organisation of tendering rounds for operation of public transport services, forum(s) for development of quality and safety standards for the service	Interface to the ticketing system of the public transport authority, interface(s) to the traveller information system	Revenue from public transport tickets, municipal, regional or government subsidies for public transport
Company perspective	Cost structure Vehicle acquisition (purchase or leasing cost etc.), operation of automated shuttles (vehicle monitoring, remote vehicle operation), repairs and maintenance (cleaning, vehicle repairs, scheduled maintenance)	Key resources Automated vehicle fleet (automated shuttles), control centre, staff qualified for automated vehicle operation and maintenance	Key activities operation and monitoring a fleet of automated shuttles, vehicle maintenance (scheduled maintenance, repairs and cleaning)	Value proposition operation of line based public transport with lower variable costs than conventional buses or minibuses.	Relationship participation in tendering rounds for operation of public transport services, participation in development of quality and safety standards for the service	Channels Installation of equipment in automated shuttles (positioning of public transport vehicles, ticketing etc.)	Revenue streams Revenue provided by contract on operating one or more public transport lines with automated shuttles
Partner perspective	Cost of providing automated vehicles, improvements to physical infrastructure required by automated shuttles, share of co	Automated vehicles, equipment and software platform for the control centre, improvements to physical infrastructure, mobile networks	Development and manufacturing of automated vehicles (shuttles), provision of support services for fleets (e.g. equipment and software platform of the control centre)	Opportunity to sell a fleet of automated vehicles instead of one vehicle and to provide support services for the vehicle operator.	Demonstrating that automated shuttles meet applicable safety standards, providing specifications for automated shuttles (e.g. infrastructure requirements, suitable operating environments and performance data)	In-vehicle interfaces for passenger information	Revenue from sales or leasing of a fleet of automated shuttles, revenues from support services for a fleet of automated shuttles
	Key partner (automated vehicle manufacturer, mobile network operator, other partners)						

B3, Long-haul goods transport with an automated vehicle

In business case B3, automated vehicles are used to transport goods over a long distance. Volvo has started development of automated trucks capable of transporting goods between a logistics centre and a port [5] and automated trucks have been tested in the US on routes between logistics centres of the UPS network [4, 14]. The value network related to the business case is described in Figure H.4.

Figure H.4 Long-haul goods transport with a highly automated vehicle – value network



The value network described in Figure H.4 includes two companies with the characteristics of a focal company. First, integrated logistics companies typically own the relationship with the end customer (consignor or cargo owner). Second, they also have large networks of subcontractors such as trucking companies which provide services on the individual legs of the transport route from door to door. On the other hand, the automated truck manufacturer integrated with the automated truck operator may also exhibit the characteristics of a focal company. This applies to situations in which the technology of automated trucks is still evolving fast, only few suppliers of new technology are available, few or no written specifications are available to describe the product, and automated trucks have not 'become a commodity'.

The automated truck operator will be a new entrant on the market of long-haul goods transport services. It will therefore face competition with conventional truck operators. Alternatively, a conventional truck operator may establish collaboration with an automated truck manufacturer to provide transport services with automated trucks in addition to manual ones. Automated trucks will also compete to lesser extent with rail transport on routes where a rail connection and suitable rail terminals are available and with inland waterways and short sea shipping on routes where both road and maritime transport connections are available. According to a recent estimate, the costs of road freight per ton kilometre may be reduced by 29–45% due to automated vehicles [15] (cost reduction of 33% or 29% estimated for 40 ton and 60 ton trucks most likely to compete with rail or inland waterways). In an analysis carried in the United States with data available for US, fully autonomous trucks have been estimated to reduce the demand for rail freight by 19–45% [16]. The business model of an integrated logistics company collaborating with an automated truck operator is described in Table H.4.

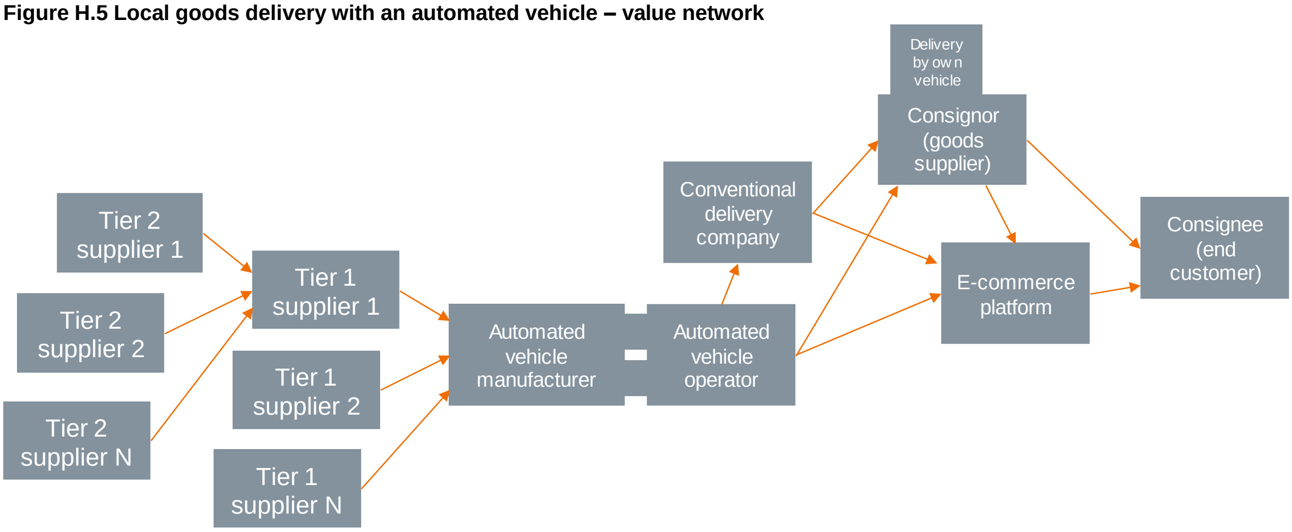
Table H.4 The business model of the an integrated logistics company utilising automated trucks, business case B3: Long-haul goods transport with a highly automated vehicle

Customer perspective	Customer (consignor or cargo owner)						
	Shipping cost (price of one or more legs) and related surcharges (documentation, container handling etc.), packaging and documentation of goods, adaptation of facilities to accommodate autonomous vehicles	Desktop or laptop computer (for preparing a shipping order), packing materials, documentation of goods	Preparation of a shipping order and documentation of goods, preparation of goods for transport, loading of goods	An integrated logistics service at competitive price	Preparation of shipping orders, online or offline	Internet connection and a computer (for preparing shipping orders), optionally: an enterprise resource management system with interfaces for logistic information	Revenues from sales of goods
Company perspective	Cost structure Fixed price for truck transport carried out with an automated vehicle, costs of other logistics operations, costs of logistics support services, overhead	Key resources Global or regional logistics network with own trucks or container vessels, container terminals, network of subcontractors and national or regional offices providing support services for logistics (customs declaration, warehousing etc.), ICT platform for logistics operations and management of shipping orders	Key activities Management of an integrated logistics network, provision of logistics services with its own resources and with subcontractors	Value proposition An integrated logistics service covering the whole logistics chain with a competitive price	Relationship Contract on shipping of goods with the consignor or cargo owner	Channels Information system for receiving shipping orders and monitoring progress of shipments (e.g. a web site, possibly also other interfaces)	Revenue streams Revenue from an integrated point to point logistics service
Partner perspective	Investment and operating cost of automated vehicles, cost of modifications to physical infrastructure	Automated vehicles capable of transporting containers or other cargo	Trucking (with automated vehicles)	Transport of goods at lower costs between logistics hubs or a logistics hub and a major customer	Provision of information on progress of shipment with an automated vehicle (e.g. positioning data)	Interface for monitoring the location of automated vehicles, interface for receiving shipping orders to be completed with automated vehicles (online or offline)	Revenues from trucking services with an automated vehicle (may be based on kilometres driven, volume of transported goods etc.)
	Key partner (automated truck manufacturer or automated truck operator)						

B4, Local goods delivery with an automated vehicle

In addition to long haul goods transport, automated vehicles may be used to provide local goods delivery services. For example, highly automated vehicles providing local delivery (e.g. groceries, pizza or medicine) are being developed e.g. by Nuro Inc. [6, 7]. The vehicles have been approved to operate on public roads in California [17], and they have been used to deliver supplies inside a field hospital [18]. Small autonomous vehicles are also being tested by Starship Technologies [19] in UK to deliver groceries [8]. A simplified value network of the business case is described in Figure H.5.

Figure H.5 Local goods delivery with an automated vehicle – value network



At least in the beginning, the automated vehicle manufacturer will be closely integrated with the automated vehicle operation. When acting together, they will have certain characteristics of a focal company in the supply chain. On the other hand, the customers of the automated vehicle operator are likely be able to substitute the service of the automated vehicle operator (e.g. by using a conventional delivery company or organising delivery with their own vehicles), may also have substantial market power themselves (e.g. major e-commerce platforms or supermarket and restaurant chains with large market shares) and will have a direct relationship with the end customer. In case of groceries, it was assumed that the goods supplier (a supermarket chain or other major retailer) would be a key stakeholder and a focal company in the business model. The anticipated business model of a major goods supplier (e.g. supermarket chain other major retailer) utilising delivery with an automated vehicle is described in Table H.5.

Table H.5 Business model of a goods supplier (supermarket chain or other major retailer) utilising delivery with an automated vehicle, business case B4: Local goods delivery with an automated vehicle

	Customer (customers in the business model)						
Customer perspective	Price of goods purchased (e.g. groceries or fast food), shipping cost if not included in the price of the main product	Delivery address, smartphone for interacting with the e-commerce platform of the consignor, credit card or online banking credentials for payment	Ordering of goods via online platform, payment with credit card or online banking credentials, receiving goods delivered by an automated vehicle	Ease of shopping (no need to visit a shop), large selection of products and low prices provided by an online retailer, low shipping cost (or shipping cost embedded in product prices)	Registration to the e-commerce platform, ordering of goods online, payment with electronic means	Computer or smartphone (for use of the e-commerce platform), address for delivery of goods	- (not applicable to most consumer products)
Company perspective	Cost structure Cost of goods sold (e.g. groceries), costs of e-commerce platform, shipping cost (delivery by automated vehicle operator, delivery by own vehicle or by conventional delivery company), marketing costs and overhead	Key resources Warehousing and logistics infrastructure for goods being sold (e.g. groceries), retail shops, e-commerce platform, brand	Key activities Online sales to consumers (e.g. groceries), logistics, management of brand and supplier network	Value proposition Large selection of goods at low prices available in an online shop, with fast delivery and low shipping cost (unless shipping cost is embedded in product prices)	Relationship operation and maintenance of an e-commerce platform (used for sales to customers), providing information on delivery times and shipment progress	Channels e-commerce platform (web site)	Revenue streams Revenues from sales of products (e.g. groceries), shipping fees (if not embedded in product prices)
Partner perspective	investment cost in automated vehicles used for local delivery of goods, operation and maintenance of automated vehicles	Automated vehicles used for local delivery of goods	Local delivery of goods (e.g. groceries) from the warehouse of the focal company to the consumer	Opportunity to provide transport services with a large fleet of automated vehicles concentrated in a limited geographical area	provision of information on estimated delivery times, delivery status and shipment progress	User interface of the autonomous vehicle used for delivery (e.g. for completing procedures required to receive goods and unload them from vehicle)	Revenues from local deliveries provided with automated vehicles (may be based e.g. on number of deliveries, value of goods delivered etc.)
	Key partner (partners in the business model)						

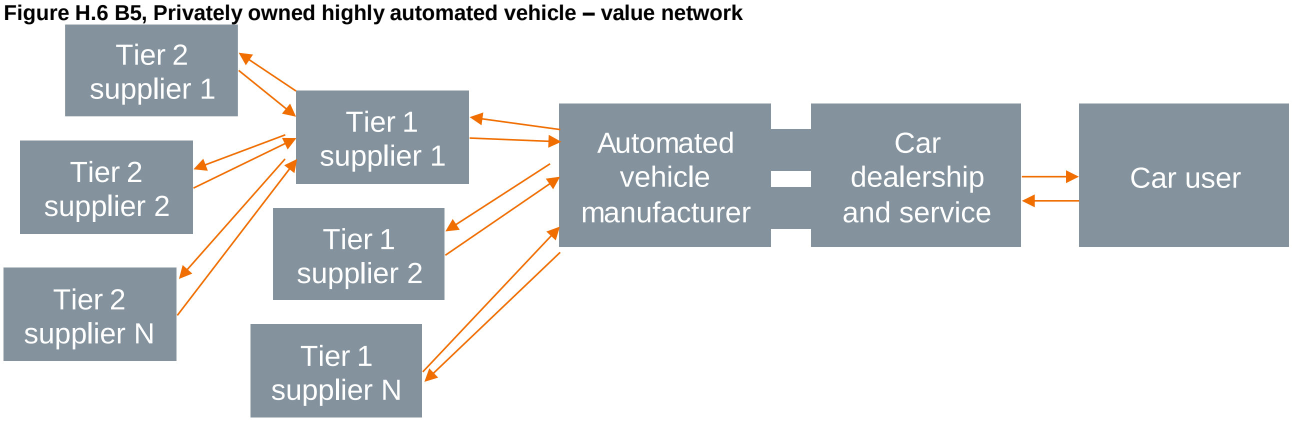
B5, Privately owned highly automated vehicle – description of business case

In this business case, most highly automated vehicles will be privately owned or provided as a service by the vehicle manufacturer. The business case corresponds to the current paradigm of vehicle ownership which includes both cars owned or leased by consumers and other car users. As in the current situation, vehicle manufacturers maintain or establish their dealer networks which not only sell or lease new vehicles to consumers but provide vehicle maintenance services and spare parts. The vehicle manufacturer retains its position as a focal company in the value network.

Existing tools to ensure safety of vehicles such as type-approval, quality control by vehicle manufacturer and its suppliers and tests by (EURO)NCAP will remain, but also new methods will be introduced such as analysis of data generated during automated vehicle operation. For example, it may be mandatory for the operator of the automated vehicle to record and disclose the situations in which the automated mode of an automated vehicle has disengaged and released the control of the vehicle to a human user [20]. The need for motor insurance with third party liability coverage may decrease if the driver is not controlling the vehicle most of the time or not at all.

It is currently not certain how the costs of accidents caused by highly automated vehicles will be covered. Possible outcomes include continuation of the current model in which the vehicle is owned and insured by the user or a business model in which the vehicle manufacturer provides the vehicle as a service and takes also responsibility for accidents (e.g. by self-insuring or in collaboration with an insurance company) [21]. In the latter case, the vehicle manufacturer would likely be responsible also for vehicle repairs and maintenance in a way comparable to vehicle leasing contracts already offered today by financing companies affiliated with vehicle manufacturers. The vehicle manufacturer would likely use its own dealership networks to organise tasks related to vehicle maintenance and repair or outsource these tasks to independent vehicle repair shops with sufficient capabilities. Only spare parts and materials provided by the vehicle manufacturer would be used in vehicle maintenance. Over the long term, revenues of aftermarket spare part manufacturers and independent car parts wholesalers and retailers may be reduced. The anticipated value network describing the business case is described in Figure H.6.

Figure H.6 B5, Privately owned highly automated vehicle – value network



In this business model, the vehicle manufacture is assumed to be the key stakeholder and the focal company. The business model of the vehicle manufacturer is described in Table H.6.

Table H.6 Business model of the vehicle manufacturer, business case B5: privately owned highly automated vehicle.

	Customer (private car user)						
Customer perspective	- Vehicle purchase price (incl. taxes) - Vehicle servicing and maintenance - Finance cost (of vehicles bought on credit)	- Vehicle purchase price - Payments for vehicle service and maintenance - Payments for other aftersale services (e.g. finance or insurance)	- Vehicle selection and purchase - Vehicle operation	More comfortable travel by car, especially over long distances, and mobility enabled by car use without a driving license	- Customer relation with the vehicle dealership - Use of online services enabled by the connected vehicle	- Residential address (for receiving mail) - email - telephone - user interface of connected and automated vehicle	- Usually no direct revenues captured by private car users - Indirect financial benefits possible (e.g. housing in a more affordable location with a longer commuting distance, no need for hotel stay during long road trips etc.)
Company perspective	<u>Cost structure</u> - Cost of developing a highly automated vehicle (largely fixed) - Manufacturing cost (mostly variable) - Marketing, brand management, overhead - Financing cost - Product liability	<u>Key resources</u> - Knowledge of design and validation of automated vehicles - Expertise in vehicle design, supplier management and brand management - Established sales and aftersales networks	<u>Key activities</u> - Design of highly automated vehicle - Vehicle manufacturing, in collaboration with the supplier network - Management of vehicle brand, sales and aftersales networks - Management of regulatory approvals	<u>Value proposition</u> Highly or fully automated vehicle with high level of safety, enabling more comfortable travel and mobility allowed by car use without a driving license	<u>Relationship</u> - Advertising to existing and potential new customers - Communication with various stakeholder groups (investors, suppliers, regulators etc.) - Management of vehicle retailer, service and maintenance and aftersales network - Financing of vehicle purchase	<u>Channels</u> - Vehicle sales, service and maintenance network - Online services enabled by the connected vehicle	<u>Revenue streams</u> - Vehicle sales price - Vehicle service and maintenance - Vehicle related services (insurance, finance etc.) and aftermarket goods (e.g. spare parts)
Partner perspective	- R&D of components and subsystems for automated vehicles - manufacturing cost of components and subsystems - logistics costs - cost of staff and facilities for vehicle sales, servicing and maintenance	- Components and subsystems - Vehicle retail, service and aftersales networks (incl. staff and facilities) - Capital, for financing of vehicle purchase	- Development and manufacturing of components and subsystems - Retail sales, incl. Vehicle service and maintenance - Provision of network connectivity - Financing	- Potential mass market for existing subsystems, components and support services - Potential mass market for new high-value subsystems and components - Exclusive rights for sale, repair and maintenance of vehicles of a given brand in a geographical region	- Vehicle service, maintenance and aftersales network - Manufacturing of spare parts and supplies	- Mobile network connectivity - User support and service centre (managed by tier1 or tier2 supplier)	- Revenues from components and subsystems - Revenues from vehicle maintenance and repair - Interest on financing provided for vehicle purchase - Charges for use of mobile network - Margin on sales of new vehicles
	Key partners (tier 1 and tier 2 suppliers, financiers, car dealerships, mobile network operators)						

Potential social impacts of these business models

Impacts on markets of products and services

The impacts of the business models described in business cases B1-B5 on the markets of products and services are described in Tables H.7–H.11.

Table H.7 Impacts on markets of products and services – Highly automated vehicle as a robotaxi

Change related to CAD	Market	Description of impact	Stakeholders affected
Robotaxi (SAE4-SAE5) operator enters an existing market of taxi services. A robotaxi can operate without a human driver on board, and this can be expected to reduce the cost of a taxi ride more than automation increases the capital costs of providing the service.	Market of taxi services	Competition on the taxi can be expected to intensify, when a new player enters the market.	Taxi companies
A robotaxi can operate without a human driver on board. This can be expected to reduce the cost of a taxi ride more than automation increases the capital costs of providing the service.	Long distance public transport services	A taxi ride is a complementary product to many long distance public transport trips (e.g. air, rail or long-distance bus), as taxi may be the only transport option for covering the last mile or it may be preferred by the traveller. Reduction in the cost of the last mile part of the journey may make transport options based on public transport more attractive.	Rail operators, airlines, long-distance bus companies
Robotaxi (SAE4-SAE5) operator provides a transport service that may act as a substitute for local public transport (bus or train). A robotaxi can operate without a human driver on board, and this can be expected to reduce the cost of a taxi ride more than automation increases the capital costs.	Local public transport services	Taxi services may become more attractive in relation to public transport, especially when ticket prices are high, public transport is infrequent or more than one person travels together.	Public transport operators (rail, bus), public transport authorities
Establishing a robotaxi service requires (1) access to new technology and (2) sufficient number of vehicles to allow monitoring and operation of vehicles to be carried out in an efficient manner by a control centre. From economic efficiency point of view, the optimal size of a robotaxi operator may be larger than the optimal size of a conventional taxi company.	Market of taxi services	The market power of the taxi operator may increase.	Robotaxi operator, conventional taxi operator, traveller
A robotaxi can operate without a human driver on board. In this case, there will be no driver who	Market of taxi services	When robotaxis enter the market of taxi services, a large share of taxis available for use will be unsuitable	Travellers

Change related to CAD	Market	Description of impact	Stakeholders affected
would be capable of assisting the passenger to board or leave the vehicle, assisting passengers with special needs (if the passenger uses a wheelchair, the wheelchair must be secured to the vehicle during transport), or to address special requirements related to transporting persons belonging to vulnerable groups (e.g. unaccompanied minors).		for persons needing assistance when boarding the vehicle, persons with special needs (e.g. travelling with a wheelchair) and for travellers belonging to certain vulnerable groups (e.g. unaccompanied minors who need to be escorted to their destination). Unless action is taken by the robotaxi operator or the regulator of taxi services, availability of taxi services for these groups may be reduced.	
Safe operation of highly automated and fully autonomous vehicles (SAE4 and SAE5) is likely to require changes to physical infrastructure (e.g. safe harbours where an automated vehicle can be safely stopped by automation) and roadside systems (mobile network connectivity, C-ITS, positioning etc.)	Construction services, equipment installation services, ICT services	Changes to physical infrastructure (e.g. safe harbours or dedicated lanes) may be needed where highly automated and fully autonomous vehicles are allowed to operate. In addition, mobile network connectivity and roadside systems may be needed. More demand is created for construction, equipment installation and ICT services.	Construction companies, equipment installation companies, ICT service providers, mobile network operators, road infrastructure managers (road operators and cities)

Table H.8 Impacts on markets of products and services – Automated shuttle providing a local public transport service

Change related to CAD	Market	Description of impact	Stakeholders affected
Safe operation of highly automated and fully autonomous vehicles (SAE4 and SAE5) is likely to require changes to physical infrastructure (e.g. safe harbours where an automated vehicle can be safely stopped by automation) and roadside systems (mobile network connectivity, C-ITS, positioning etc.)	Construction services, equipment installation services, ICT services	Changes to physical infrastructure (e.g. safe harbours or dedicated lanes) may be needed where highly automated and fully autonomous vehicles are allowed to operate. In addition, mobile network connectivity and roadside systems may be needed. More demand is created for construction, equipment installation and ICT services.	Construction companies, equipment installation companies, ICT service providers, mobile network operators, road infrastructure managers (road operators and cities)

Change related to CAD	Market	Description of impact	Stakeholders affected
In future, line-based public transport can be operated at lower cost with automated shuttles with no human driver onboard. This applies especially to situations with thin passenger flows such as low-density environments and off-peak times (e.g. nighttime).	Public transport operation, public transport services	Increase in efficiency may be used by public transport authorities to improve service coverage or frequency or reduce ticket price paid by the traveller.	public transport authorities, travellers
When implemented as a highly automated vehicle, an automated shuttle does not require a driver or other person on board in every vehicle.	Ticketing systems and ICT services for public transport	When the vehicle has no driver or other staff on board, ticket control and controlling access to the vehicle can no longer be based on methods requiring manual work. Demand for electronic ticketing and access control systems can be expected to increase.	Public transport operators, ticketing system suppliers
When implemented as a highly automated vehicle, an automated shuttle does not require a driver or other person on board in every vehicle. When the vehicle has no driver or other staff on board, tasks related to security of passengers and prevention of vandalism have to be organised in other ways. Monitoring the security of passengers inside the vehicle and detection of possible incidents of vandalism will probably be carried out by the control centre ("control tower") monitoring a fleet of automated shuttles.	Private security services	Mobile security patrols may be needed in the area where automated shuttles are operating (private security company or police). Additional demand for private security services may be created when automated shuttles without staff on board are introduced.	Private security companies
When implemented as a highly automated vehicle, an automated shuttle does not require a driver or other person on board in every vehicle. In case of a breakdown of the vehicle or any failure of the automation system, there will be no one in the vehicle to inform and assist the passengers or to warn other road users of a stopped vehicle.	Field support services	Breakdowns of automated shuttles and failures of the automation system need to be managed in a way which ensures the safety of passengers and other road users. This is likely to require a control centre with an advanced software platform which allows determining an optimum response to various types of incidents as well as a mobile technical support team. Technical support services for automated shuttles may be provided by the vehicle operator itself or an external service provider (in a way similar to contractors maintaining	Maintenance contractors, towing companies

Change related to CAD	Market	Description of impact	Stakeholders affected
		elevators or vehicle towing companies).	
When implemented as a highly automated vehicle, an automated shuttle does not require a driver or other person on board in every vehicle. The time based variable cost of an automated shuttle is therefore lower than the corresponding cost of a bus or minibus of similar size. This is likely to make line based public transport economically more viable even in case of thin passenger flows (cases in which the number of passengers is too low for a bus line).	Market of public transport services	In geographical areas and periods of low demand, automated shuttles can potentially serve as feeders to rail stations or other public transport lines (e.g. tram). The accessibility of rail stations or other public transport terminals is likely to improve. For operators of tram, heavy rail or trunk bus lines, this involves an opportunity to increase their revenue and number of passengers.	Rail operators, public transport authorities, bus companies (operating trunk lines)

Table H.9 Impacts on markets of products and services – Long-haul goods transport with a highly automated vehicle

Change related to CAD	Market	Description of impact	Stakeholders affected
A highly automated truck is capable of transporting goods without a human driver on board. This means also that there is no human user on board managing the shipping documents or capable of presenting them for inspection when necessary.	ICT services, software	The company operating an autonomous truck, or its customer, must have an information system which is capable of handling electronic freight documentation (e.g. electronic waybills). Digitalisation can be expected to accelerate in road freight sector. This creates new business opportunities for software and ICT services companies.	ICT service providers, software companies, truck operators
A highly automated truck is capable of transporting goods without a human driver on board. The cost of road freight per ton kilometre may be reduced when compared to other modes of transport (e.g. rail).	Long-haul freight market	Cargo flows between terminals or between a major customer and a cargo terminal may be transferred to road from rail and waterborne transport. Share of freight carried by rail or by waterborne transport may be reduced. This applies especially to routes on which automated vehicles are likely to appear first and on which road freight already competes with rail or waterborne transport.	Rail operators, shipping companies

Change related to CAD	Market	Description of impact	Stakeholders affected
A highly automated is capable of transporting goods without a human driver on board. It will therefore have a cost advantage over manually operated trucks [15] on routes where automated driving is feasible.	Long-haul freight market	Competition of trucking companies will intensify on routes where automated driving is feasible. In the long term, companies with manual trucks may be forced to adopt automation or be displaced by companies with highly automated or autonomous trucks.	Trucking companies, logistics companies
In case of a conventional truck, the presence of a human driver is likely to deter crime against the vehicle and its cargo (e.g. theft of cargo). In a highly automated truck, there is no human driver capable of detecting, preventing or reporting crime against the vehicle or cargo.	Alarm systems, private security services	Solutions are needed to prevent theft of cargo and theft of fuel from vehicles, especially when the cargo is valuable and can be easily converted to money. Automated trucks transporting valuable cargo or operating in high-crime areas may need an electronic alarm system or other systems protecting the vehicle and the cargo and mobile security patrols responding to detected incidents. This is likely to create a new market for ICT system developers (alarm systems) and private security companies (mobile security patrols).	ICT system developers, private security companies
Safe operation of highly automated and fully autonomous vehicles (SAE4 and SAE5) is likely to require changes to physical infrastructure (e.g. safe harbours where an automated vehicle can be safely stopped by automation) and roadside systems (mobile network connectivity, C-ITS, positioning etc.)	Construction services, equipment installation services, ICT services	Changes to physical infrastructure (e.g. safe harbours or dedicated lanes) may be needed where highly automated and fully autonomous vehicles are allowed to operate. In addition, mobile network connectivity and roadside systems may be needed. More demand is created for construction, equipment installation and ICT services.	Construction companies, equipment installation companies, ICT service providers, mobile network operators, road infrastructure managers (road operators and cities)

Table H.10 Impacts on markets of products and services – Local goods delivery with an automated vehicle

Change related to CAD	Market	Description of impact	Stakeholders affected
Local goods delivery with a highly automated vehicle does not require a human driver onboard.	Consumer products (e.g. groceries)	The cost of providing local delivery service for goods ordered online or offline can be expected to be reduced. An online retailer with capability to use automated vehicles for delivery will probably have lower shipping costs than other online retailers and will therefore have a competitive advantage.	Online retailers, retailers
Local goods delivery with a highly automated vehicle does not require a human driver onboard.	Consumer products (e.g. groceries)	The cost of providing local delivery service for goods ordered online can be expected to be reduced. When the cost of local delivery is reduced, online shopping will become more attractive when compared to shopping trips to retail shops (e.g. supermarkets or shops in shopping malls).	Retailers (e.g. supermarkets, specialty retailers), shopping malls
Local goods delivery with a highly automated vehicle does not require a human driver onboard.	Transport services (especially: local delivery and last mile transport)	The time based variable cost of delivery services based on automated vehicles is lower than the corresponding cost of delivery services provided by a vehicle and a human driver. Local goods delivery implemented with an automated vehicle may have a positive gross margin at lower prices than delivery service provided with a conventional vehicle and a human driver. Competition may become more intense in the local and last mile delivery services.	Transport companies (providing local or last mile delivery)
Local goods delivery with an automated vehicle requires collaboration with an automated vehicle operator or an e-commerce platform with its own warehouse and automated vehicles. At least in the beginning, these options are not available to small online or offline retailers with fair terms and conditions or not at all.	Consumer products (e.g. groceries)	Small online retailers will have an increased need to partner with an e-commerce platform providing warehousing and delivery with an automated vehicle to be able to offer products with competitive shipping costs. The competitive position of small online and offline retailers may be weakened.	Retailers (small)

Change related to CAD	Market	Description of impact	Stakeholders affected
Safe operation of highly automated and fully autonomous vehicles (SAE4 and SAE5) is likely to require changes to physical infrastructure (e.g. safe harbours where an automated vehicle can be safely stopped by automation) and roadside systems (mobile network connectivity, C-ITS, positioning etc.)	Construction services, equipment installation services, ICT services	Changes to physical infrastructure (e.g. safe harbours or dedicated lanes) may be needed where highly automated and fully autonomous vehicles are allowed to operate. In addition, mobile network connectivity and roadside systems may be needed. More demand is created for construction, equipment installation and ICT services.	Construction companies, equipment installation companies, ICT service providers, mobile network operators, road infrastructure managers (road operators and cities)

Table H.11 Impacts on markets of products and services – Privately owned highly automated vehicle

Change related to CAD	Market	Description of impact	Stakeholders affected
A highly automated or fully autonomous vehicle can potentially be used in a more flexible way by members of a household or employees of a company with a car. For example, a car used for commuting to work may be used for other purposes by somebody else in the same household during the working day. This applies to situations in which the car is capable of moving on the road network without a driver (SAE5 vehicle or SAE4 vehicle with remote operation).	Vehicle market (cars, vans)	The need to have more than one car in the same household (or the same company) may be reduced. In this case, car dealerships will sell a smaller number of vehicles. The impact on revenue and gross margin is uncertain, as it is not known yet whether the decrease in sales volume will be compensated by increase in average price of a new vehicle and increase in average gross margin.	Car dealerships
Smaller number of vehicles may be sold when most vehicles are automated. This will occur if automated vehicles are used more intensively than conventional ones, and the increase in vehicle kilometres travelled will not compensate the increasing kilometrage per vehicle.	Market of vehicle components and subsystems	The impact on tier 1 and tier 2 suppliers will be uneven. Demand for some components will be reduced. This applies especially to components lasting the whole lifetime of the vehicle and not significantly affected by wear due to increased kilometrage per vehicle.	Tier 1 and tier 2 suppliers
Highly automated vehicles will include components and	Market of vehicle components	Demand for new high-value vehicle components and subsystems	Tier 1 and tier 2 suppliers

Change related to CAD	Market	Description of impact	Stakeholders affected
subsystems not used in most current vehicle models.	and subsystems	required in CAD vehicles will appear.	
Safe operation of highly automated and fully autonomous vehicles (SAE4 and SAE5) is likely to require changes to physical infrastructure (e.g. safe harbours where an automated vehicle can be safely stopped by automation) and roadside systems (mobile network connectivity, C-ITS, positioning etc.)	Construction services, equipment installation services, ICT services	Changes to physical infrastructure (e.g. safe harbours or dedicated lanes) may be needed where highly automated and fully autonomous vehicles are allowed to operate. In addition, mobile network connectivity and roadside systems may be needed. More demand is created for construction, equipment installation and ICT services.	Construction companies, equipment installation companies, ICT service providers, mobile network operators, road infrastructure managers (road operators and cities)
Privately owned fully autonomous (SAE5) vehicles and highly automated vehicles (SAE4) that are remotely operated can be used by groups which are now 'captive users' of public transport.	Market of transport services	Public transport will have less 'captive users'. Taxi services will have a new competitor in one market segment of taxi services (travellers with no driver's license). Revenue of public transport and taxi services may be reduced, especially in situations in which highly automated and privately owned vehicles compete against infrequent conventional bus services and conventional taxis.	Public transport operators, taxi services
A highly automated vehicle requires only minimal or no effort for the driving task.	Road infrastructure, property market	When no effort is required for driving, long commute from home to work by car will likely be perceived as less inconvenient. Commuters may compensate this by accepting a longer distance between home and workplace. An increase in road capacity will be needed. Property prices in remote but otherwise desirable neighbourhoods may increase. Property prices will decrease or rise more slowly in urban areas with good accessibility by road or public transport but otherwise less preferable characteristics.	Road infrastructure manager, property owner, cities
A highly automated vehicle requires only minimal or no effort for the driving task.	Hospitality	Travelling with a highly automated (SAE4) or fully autonomous (SAE5) vehicle will allow passengers to be	Motels, hotels focusing on car travellers

Change related to CAD	Market	Description of impact	Stakeholders affected
		involved in secondary activities such as resting (SAE4: potentially, SAE5: yes). When travelling long distances by car, there may be less need to stay overnight at hotels or motels.	
Highly automated vehicles will likely act as data sources for the vehicle manufacturer's R&D department. On the other hand, highly automated vehicles are likely to receive software and hardware updates during the vehicle life span, for example to address identified safety issues.	Vehicle market (cars and vans, relation between vehicle manufacturer and car dealerships)	The vehicle manufacturer will likely establish vehicle sales, service and maintenance network by itself in major market areas or establish close collaboration with a stakeholder that has facilities, staff and competence for vehicle sales, maintenance and repair.	Automated vehicle manufacturers, car dealerships
The human driver will control an automated vehicle only when requested to do so (SAE4) or not at all (SAE5).	Vehicle insurance market	It will be less and less possible to attribute the liability for any accidents to the negligence of the driver. The number of accidents may also be reduced, if accidents caused by human error are reduced, and the number of other accidents does not increase to compensate this. Over the long term, need for motor insurance paid by the owner of the vehicle may decrease (the liability part). [21]	Insurance companies
The human driver will control an automated vehicle only when requested to do so (SAE4) or not at all (SAE5).	Vehicle insurance market	It may be more difficult to attribute liability for accidents to the negligence of the driver, and the manufacturer of the automated vehicle will be exposed to product liability. Possible outcomes include e.g. insurance taken by the vehicle owner (the current model), personal injury and accident liability coverage provided by the vehicle manufacturer (by self-insuring or in collaboration with an insurance company) or a no-fault regime for compensating the cost of traffic accidents. The vehicle manufacturer may also be held liable for product defects of the automated vehicle. [21]	Insurance companies, vehicle manufacturers
The human driver will control an automated vehicle only when requested to do so (SAE4) or not at all (SAE5).	Entertainment, news, social media	Travelling with a highly automated vehicle will allow passengers to be involved in secondary activities such as use of online services or	Entertainment, news, social media companies

Change related to CAD	Market	Description of impact	Stakeholders affected
		entertainment (SAE4: potentially, SAE5: yes). Use of online services (e.g. entertainment and news) during trips made by car will likely increase.	
A highly automated vehicle (SAE5) does not need a human driver for transporting goods from one point to another, even though loading and unloading by a human person may be needed.	Retail (e.g. groceries, medicine)	An automated vehicle (SAE5) allows goods ordered online to be picked up from seller's warehouse without the buyer being present (e.g. groceries or medicine). The buyer does not need to use his or her time anymore for this. The number of shopping trips to supermarkets and shopping malls may decrease; this applies especially to consumers with limited time budget. In the long term, a new retail concept may evolve and the existing ones may be affected.	Online retailers, shopping malls, supermarkets, pharmacies
In a highly automated vehicle (SAE4-SAE5), vehicle occupants do not need to focus on the driving task most of the time or at all. The time used for driving in the past will be available for secondary activities e.g. work or entertainment.	Vehicle market, market of entertainment and media	Automated vehicle has potential to become a platform for entertainment and consumption of media or a mobile office.	Vehicle manufacturers, entertainment and media companies
The human driver will control an automated vehicle only when requested to do so (SAE4) or not at all (SAE5).	Market of long-distance public transport services	The distance to be travelled by car during one day will not be limited by the fatigue of a human driver like in case of a non-automated vehicle. Relative attractiveness of traveling by car may increase for trips that can be travelled by car in a time accepted by the traveller but are perceived to be exhausting to drive. Private car becomes even stronger competitor of rail and bus services.	Rail and bus operators

Impacts on new work environments and work patterns

The impacts of CAD on new work environments and work patterns can be expected to be related to both the business cases to be realised, the business models applied by key stakeholders, characteristics of the technology and the context in which CAD is implemented. While all potentially relevant impacts on new work environments and work patterns are difficult to predict, a summary of impacts foreseen at the moment is presented in this chapter.

First, highly automated and fully autonomous vehicles can be operated without an intervention by human user most of the time (SAE4) or at all (SAE5). This allows the human user to be involved in other activities such as office work. On the other hand, travelling from one place to another is likely to remain as a regular activity in many businesses (e.g. to participate in meetings, to provide services to customers, to maintain or install equipment etc.). It therefore seems possible that a highly automated or fully autonomous vehicle will be used as a temporary or secondary office space. In other words, a working space of a new type may be introduced to a large number of professions.

Automated driving is likely to affect professions in which most of the work is carried out at customer's premises, and a usual working day involves visiting multiple locations (e.g. delivery and installation of large household appliances, lift maintenance contractors etc.). If autonomous vehicles (SAE5) are introduced, driving will not be a part of the work anymore. In practice, this means that the travel time can be used for resting, office work or other secondary activities. It also means that the length of the working day is no more limited by the legislation that restricts the maximum number of driving hours in a day or minimum duration of breaks. Variation in the length of work shifts may therefore increase.

In some occupations, skills and qualifications to operate a heavy goods vehicle are required. This applies, for example, to waste collectors. If fully autonomous vehicles are introduced, qualifications and skills to operate the vehicle are no more required in the work. Some professions such as garbage collector may become de-qualified, and this may affect the salary and type of employment contract (in case of a garbage collector, the salary and terms and conditions of employment may approach those of a cleaner). On the other hand, operating an automated vehicle may increase the skills and qualifications required from the driver.

In case of public transport and robotaxis, automated vehicles are likely to require supervision when operating on roads and in urban environment. At times, they may also require the human user to intervene e.g. in case of an unusual traffic situation, breakdown of the vehicle or a security incident (e.g. vandalism). It seems likely that the supervision and possible remote operation of a number of automated vehicles will be carried out by a 'control tower' [22, 23]. While the tasks of the control tower can be foreseen to certain extent, the role of the control tower is still an active research topic [24]. The control tower will be new work environment but its characteristics as a workplace are difficult to predict as long as its role is not fully defined.

In long-haul goods transport, there will be much less (SAE4) or no (SAE5) need for driving after highly automated or fully autonomous vehicles have been introduced. However, a human person on board the vehicle may be required in certain situations. This may be necessary, for example, to deter theft of valuable cargo, to respond to security incidents and to guard the vehicle when it needs to be parked outside the gates of a harbour or cargo terminal. In this case, the human user on board the vehicle needs to be active when human intervention is required to operate the vehicle (situations outside the operational design domain, e.g. driving to a car ferry) or the vehicle has to be stopped in an unprotected area. It is possible that management of vehicle and cargo documents and administrative work related to logistics may be carried out by the same person on board the vehicle. In summary, the tasks carried out by the driver would become much more diverse in this scenario, and the cabin of a truck would be an office, a security control room and a hotel room.

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Annex I – Policy measures matrix

See next page.

About Ecorys

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